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AT-SEA TEST AND EVALUATION OF OXYGEN (O2) ANALYZERS.(U)

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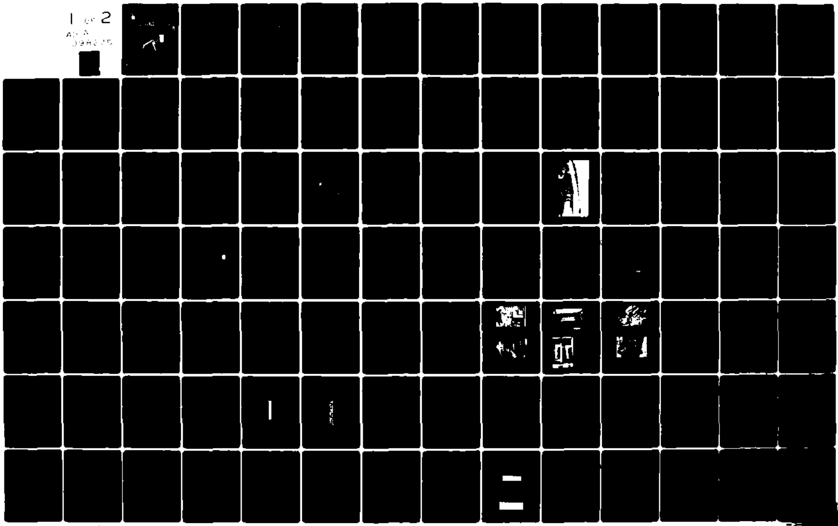

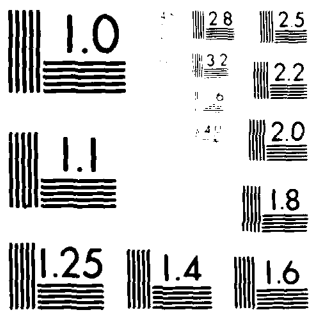

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AT-SEA TEST AND EVALUATION OF OXYGEN (O_2) ANALYZERS

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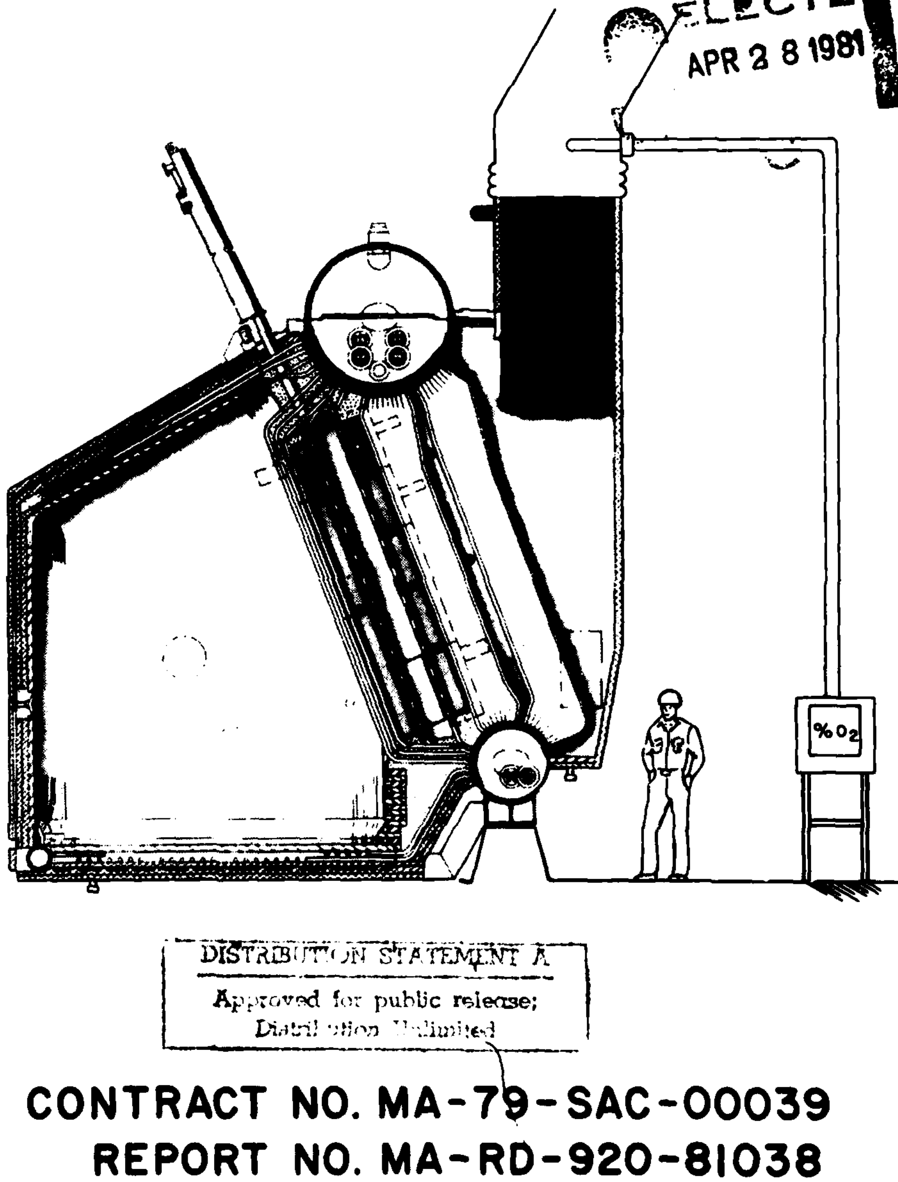

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MARITIME ADMINISTRATION

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16\. Abstract (Limit: 200 words)

This report presents the results, conclusions and recommendations derived from a continuous ten (10) month at-sea endurance test of eight (8) commercially available zirconium oxide boiler flue gas oxygen (O_2) analyzers onboard the S. S. STELLA LYKES, a modern steam turbine propelled cargo vessel owned and operated by Lykes Brothers Steamship Company, Inc. Included within is a description of the program's purpose, objectives and scope. A discussion of the technical and economic merit and potential of continuously monitoring marine boiler flue gas oxygen content as an indicator of excess air being supplied for combustion is also presented. The program's background, requirements and technical approach are discussed in detail. The report includes the identification and recommendation of installation and service related requirements for the marine application of O_2 analyzers. Finally, a recommended specification for a "marinized" continuous reading zirconium oxide based oxygen analyzer has been developed and included in the report.

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OF OXYGEN (O_2) ANALYZERS

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Prepared For:

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This program relied on the technical assistance, cooperation and dedicated effort of the following individuals who are duly noted here: Mr. Joseph Bernstein, Jr., Vice President and Mr. Lucian Castro, Assistant Manager, Maintenance and Repair, Lykes Brothers Steamship Company, Inc. and Chief Engineers Joseph Gobroski, William Thornton and Frank Pharr, and U. S. Merchant Marine Academy Engine Cadet-Midshipmen Kevin Adams, Gregory Lucarelli and Edward Fairbairn who served in the S. S. STELLA LYKES during the ten (10) month at-sea endurance test and evaluation period.

1.0 INTRODUCTION/EXECUTIVE SUMMARY

1.0 INTRODUCTION/EXECUTIVE SUMMARY

The at-sea test and evaluation of commercially available oxygen (O_2) analyzers, was conducted under the sponsorship of the U.S. Maritime Administration's Office of Research and Development and with the cooperation of Lykes Brothers Steamship Company, Inc., the operator of the test vessel. The results of this endurance test and evaluation provided considerable data that formed a basis for identifying and specifying requirements for continuous reading boiler flue gas oxygen content analyzers suitable for service in the rigorous shipboard environment.

1.1 Scope

The at-sea endurance testing of eight (8) commercially available continuous reading oxygen (O_2) analyzers conducted onboard the general cargo vessel S. S. STELLA LYKES from April, 1980, through January, 1981, was based on a detailed analysis and screening of currently available O_2 analyzer systems, the development of test requirements, methodology and criteria and the successful implementation of a five (5) phased program technical approach as presented in detail in Section 2.0 of this report. Initially, fifty (50) analyzers of different manufacture were screened. They can be categorized generically according to sensing principle including wet chemical, electro-chemical, paramagnetic, thermo-magnetic and zirconium oxide. Early on it became increasingly evident from a review of analyzer design, experience obtained from applications similar to marine boilers and user interviews that the zirconium oxide based analyzers of the extractive and in-situ types represented the test technology currently available for shipboard application. (Extractive units are placed external to the boiler uptake and require an air asperated eductive loop to draw a sample of flue gas out of the stack across the cell and back into the stack. In-situ units place the cell directly in the flue gas path in the uptake.) The eight (8) analyzers finally selected for endurance testing were zirconium oxide based O_2 analyzers.

The evaluation was conceived and implemented as an endurance test. The analyzers were installed in the boiler uptakes sampling dirty flue gas and were evaluated continuously over a ten (10) month period under typical shipboard operating conditions and monitored and supported by shipboard operating personnel, as opposed to a rigorously controlled shoreside laboratory evaluation. Each analyzer's output (% O_2) was recorded continuously by an automatic data logging system designed specifically for this evaluation. Other quantitative and qualitative data was recorded manually on a scheduled frequency. This accumulated data became the basis on which the program's objectives were formulated and achieved. The technical approach taken was that of a time phased program consisting of the following program tasks.

Task 1: Development of Test and Evaluation Methodology

Task 2: Selection and Procurement of Oxygen Analyzers

Task 3: Installation of Oxygen Analyzers

Task 4: Extended Endurance Testing of Oxygen Analyzers

Task 5: Development of Performance Data and Criteria (Specification) for Shipboard Oxygen Analyzers

Tasks 1 through 4 of the technical approach are described in detail in Section 2.0 of this report, while Task 5 is addressed in Sections 3.0 and 4.0.

1.2 Objective

The nature of the testing carried out was that of a "real world" in-service evaluation of analyzers whose implementation in related shoreside applications have proven successful but for which there was little or no data and experience available from marine boiler installations. The overall objective of the program was not to evaluate each analyzer individually and against one another to establish an order of ranking but to identify and document both the positive and negative features and aspects of each machine. This information was then used to develop a recommended specification for a marinized version of a continuous reading zirconium oxide based oxygen analyzer which adequately addresses and identifies those requirements peculiar to a typical shipboard propulsion system operating environment. A specification was developed from information obtained and/or categorized under the following criteria.

(1) In-Service Performance

(2) Repeatability

(3) Calibration and Recalibration Requirements

(4) Maintainability

(5) Repairability

(6) Environmental Influences

(7) Presentation of Reading/Information

Paragraph 4.2 of this report presents a recommended specification for the procurement and shipboard application of continuous reading zirconium oxide based oxygen (O_2) analyzers.

1.3 Summary of Results

Of the eight (8) analyzers evaluated in this program five (5) operated without failure throughout the ten (10) month shipboard endurance test phase yielding continuous test data. Of the three (3) units which experienced failures, the duration of time during which they were not functioning was 67%, 46%, and 16% for which disabling causes were determined to be a plugged sample gas asperator tubing circuit, repetitive failure of a cell heater temperature control circuit and a control cabinet electronic malfunction.

Of the five (5) units that remained in operation continuously without the need for factory service due to failure, no single unit on the basis of evaluation criteria listed in Paragraph 1.3 was found to be completey suited for marine service. However, all eight (8) units with modification or adjustment during manufacturing and/or in the field at the time of installation, could meet the specification requirements developed as a result of this program.

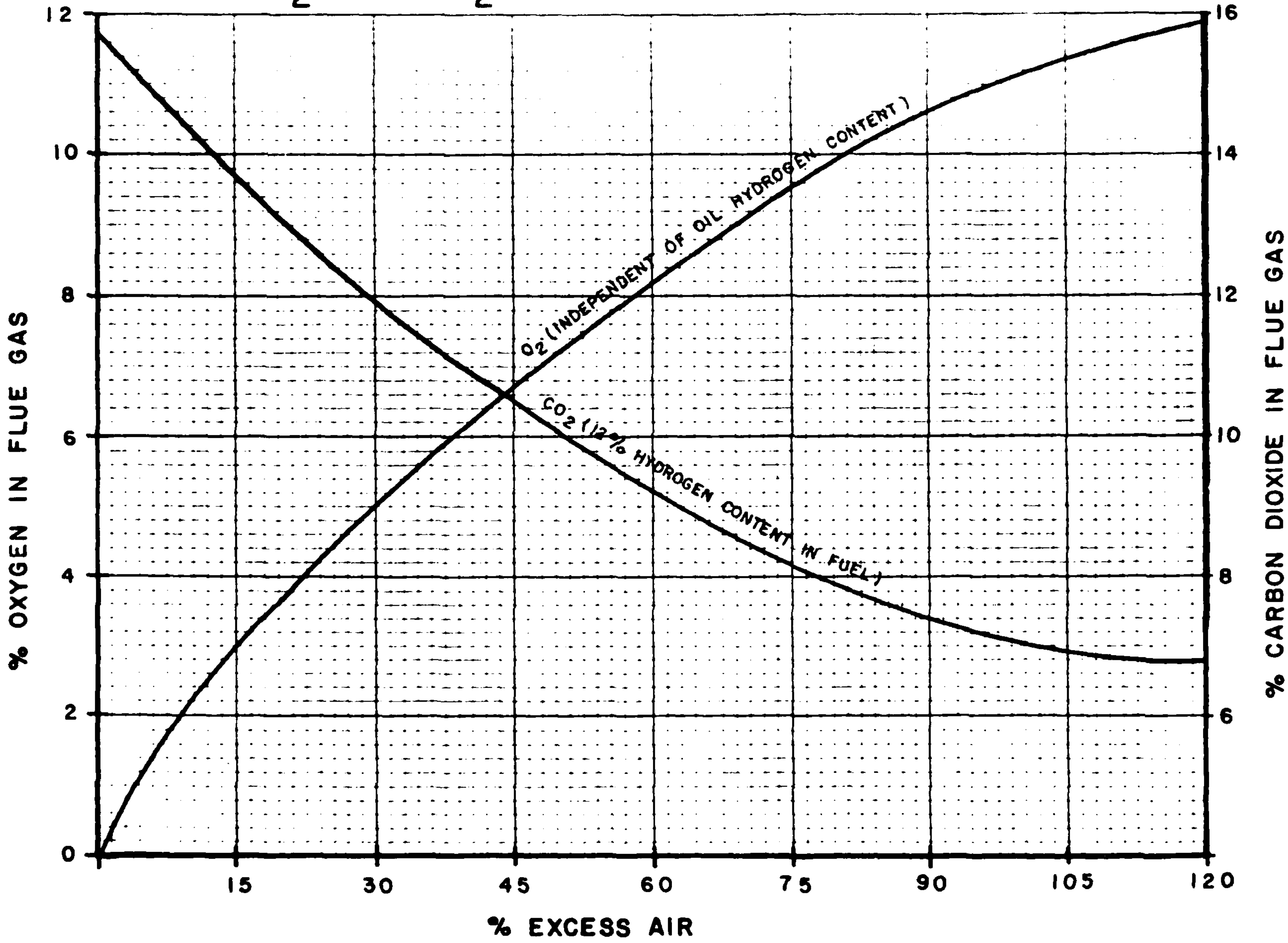
The at-sea test and evaluation of oxygen analyzers demonstrated that the zirconium oxide based oxygen sensing principle coupled with state-of-the-art miniaturized electronic components and circuitry for display and signal conditioning, properly specified and selected, can offer a reliable low cost (under $8,000.00 installed per boiler) method for continuously monitoring the oxygen content (excess air level) in exhaust gas from marine boilers.

1.4 Marine Boiler Flue Gas Analysis Background and Benefits

The analysis of boiler stack gas for its content of various components such as carbon dioxide (CO_2) or oxygen (O_2) as indicators of excess air (see Figure 1.1) supplied for the combustion of fuel in the furnace and

FIGURE 1.1

% O_2 AND CO_2 IN FLUE GAS vs % EXCESS AIR



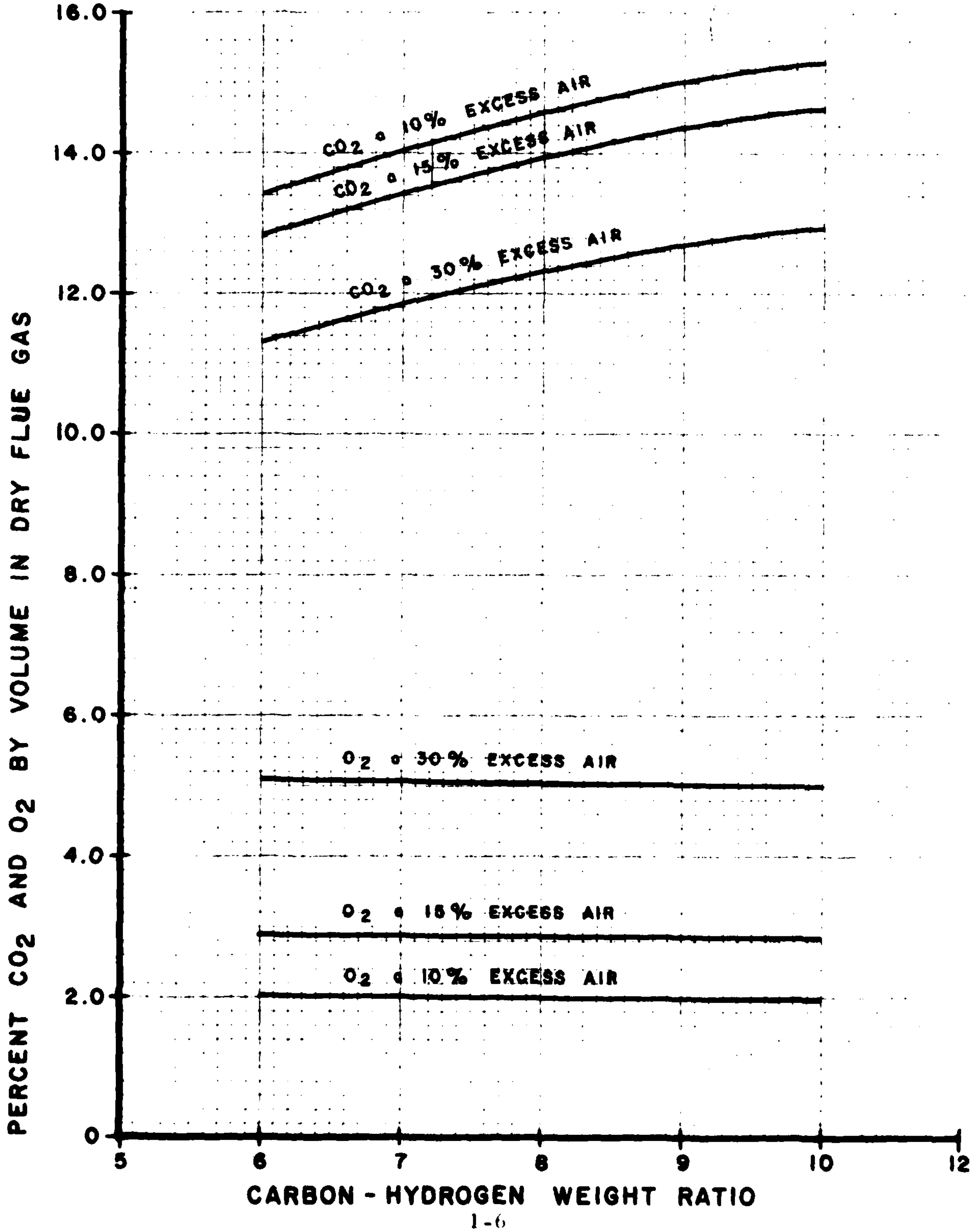
boiler efficiency, in conjunction with stack temperature, has long been an accepted standard both ashore and for marine boilers. Historically, CO_2 content in the stack gas has been used as the primary indicator of excess air supplied for combustion and ultimately, boiler efficiency. However, oxygen content in flue gas as an indicator of excess air offers a significant advantage over CO_2 in that its value as a percentage of a sample volume of fuel gas is independent of the carbon hydrogen weight ratio of the fuel oil being burned. As can be seen from Figure 1.2, at 15% excess air the CO_2 indication in the flue gas varies by 1.8% when the carbon-hydrogen ratio changes from 6 to 10. From the same carbon-hydrogen ratio change, the O_2 indication in the flue gas varies by 0.06%. The oxygen/excess air relationship's insensitivity to the carbon-hydrogen weight ratios in the fuel being burned is especially important when considering it for marine boiler flue gas analysis. This is due to the fact that a steam ship can expect to bunker and burn oils of greatly varying quality with a wide range of hydrogen content due to the transient nature of vessel operation and the usual lack of a detailed analysis of the qualities and characteristics of the fuel being supplied. Since burners are designed to fire at specified excess air levels, knowledge of the excess air level in the flue gas is important to detect burner problems and off-design operation which reduces boiler efficiency.

From a boiler operating standpoint the ability to read or monitor excess air levels continuously offers significant assistance and advantage in keeping boiler efficiency at or near optimum. Until very recently most systems for measuring both CO_2 and O_2 content in the flue gas as an excess air indicator were not suitable for monitoring these parameters on a continuous basis. Usually these readings were taken once daily aboard ship utilizing a wet chemical* analysis system. The frequency with which these readings were taken and practical problems associated with maintaining the sampling system and chemicals made this approach virtually impossible to apply to boiler operation on a continuous basis. Improvements in the reliability of continuous reading devices for flue gas oxygen content analysis were developed. These consisted mostly of paramagnetic and electro-chemical analyzers which required extensive filtering, cooling and drying sub-systems to condition the gas prior to flowing it across the primary sensor. These systems because of the constant maintenance required still presented severe problems in terms of operational reliability. The development of the zirconium oxide based oxygen analyzer sensing principle for dirty gas applications coupled with state-of-the-art electronics technology over the past five (5) years has greatly improved the operational reliability of continuously reading oxygen analyzers.

NOTE: Orsat measures O_2 "dry." Wet refers to the chemical reagents.

FIGURE 1.2

IMPACT OF FUEL OIL CARBON-HYDROGEN WEIGHT RATIO ON CARBON DIOXIDE AND OXYGEN AS INDICATORS OF EXCESS AIR



However, this recent improvement in flue gas analysis technology was not accomplished without some economic incentive. For boiler flue gas monitoring applications, this impetus has been the very steep increase in the cost of fuel oils commonly employed as boiler fuels (approximately 30% per annum over the past eight (8) years). Simply stated for a clean boiler operating at fixed steaming rate, supplying air flow for combustion which exceeds design values required for proper combustion and heat transfer (typically 15% excess air or 3% O_2 for a marine boiler) wastes fuel. This inefficiency results from the fact that the air supplied in excess of design requirements enters the furnace, is heated by the combustion process and carries heat up the stack and out of the boiler. Under normal design conditions this heat would have been transferred to water in the boiler tubes to generate steam. For every 15% of air supplied to a marine boiler for combustion in excess of design requirements, a one (1) percent decrease in boiler efficiency occurs (or a 1% increase in fuel consumption). In a clean boiler this condition can usually be correlated with an increase in final stack temperature above the design value as illustrated in Figure 1.3. For a ship similar to the test vessel, the S. S. STELLA LYKES, the installation of O_2 analyzers similar to any of those evaluated in this program and which allowed the operators to reduce excess air by 15% would result in a fuel consumption reduction equivalent to $30,000.00 per year based on calculations considering only operation at sea for 222 days per year. This savings would pay for the cost of a typical installation in less than six (6) months.

The reduction of excess air supplied for combustion also provides other more subtle benefits. These result primarily from a reduction in the amount of free oxygen available to initiate fouling and corrosion of hotter boiler superheater surfaces (see Figure 1.4). Fouling and corrosion attack of the colder economizer surfaces as a result of oxidation of sulfur due to the availability of free oxygen contained in the flue gas and the subsequent formation and condensation of sulfuric acid in these cooler boiler regions is also reduced. This relationship is illustrated in Figure 1.5 as a function of sulfuric acid dewpoint and excess air levels. The reduction of boiler heat exchange surface fouling and corrosion will also provide additional savings in maintenance and repair costs, vessel outage due to boiler related problems and potentially longer boiler component life.

FIGURE 1.3

BOILER EFFICIENCY vs STACK TEMPERATURE AS A FUNCTION OF EXCESS AIR FOR TYPICAL MARINE BUNKER C FUELS

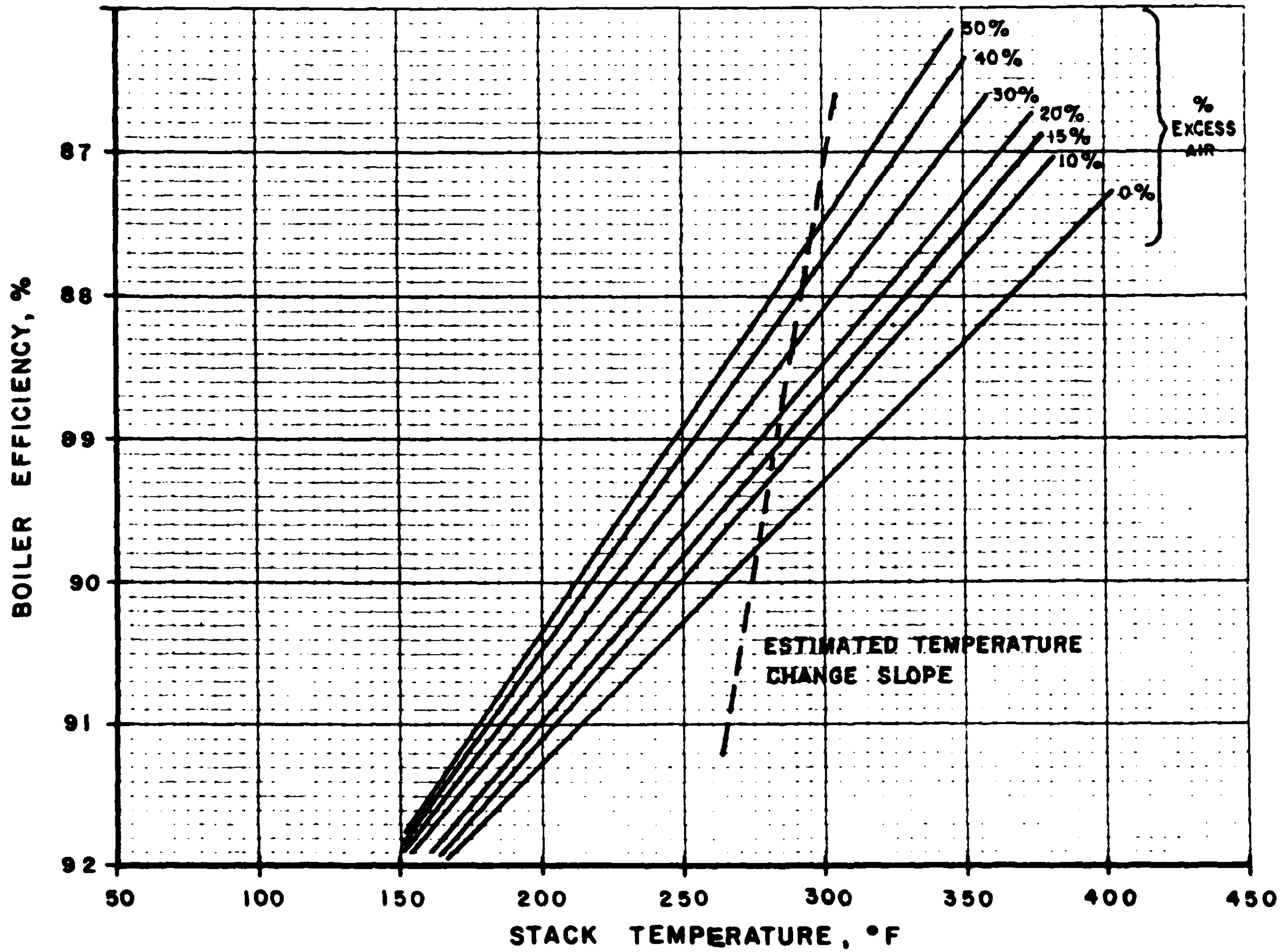


FIGURE 1.4
BOILER FOULING RATE vs SURFACE TEMPERATURE AS A FUNCTION OF EXCESS AIR

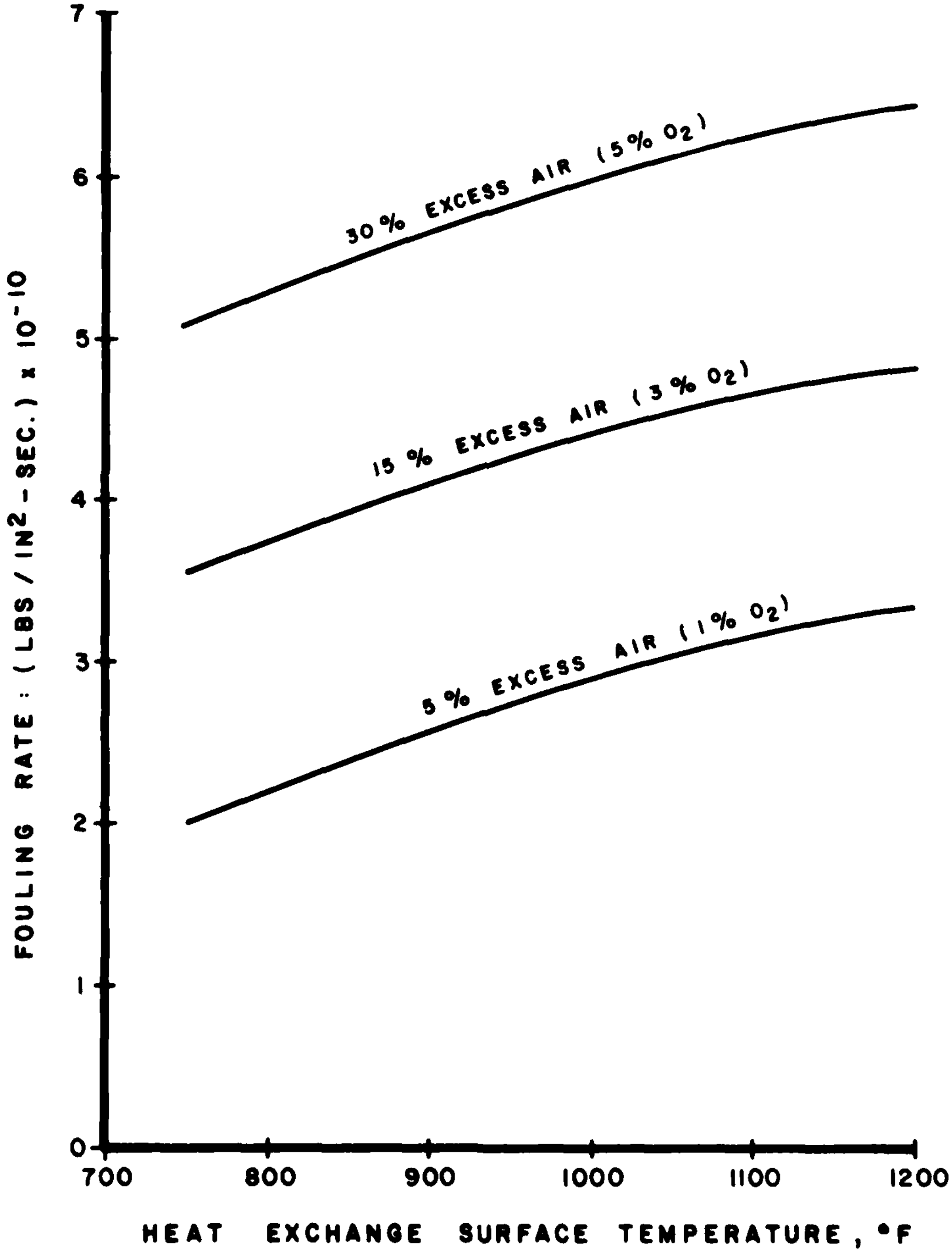
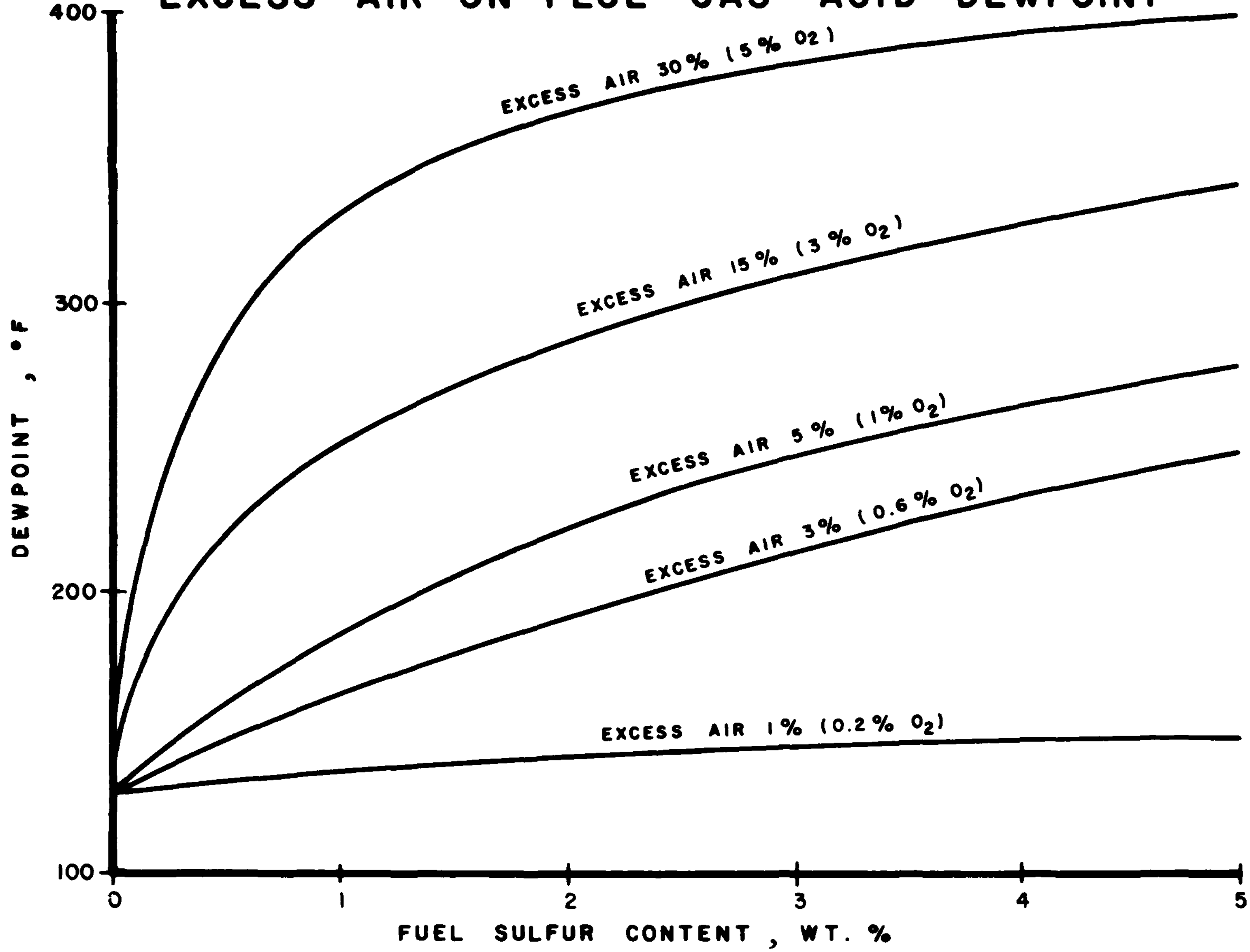


FIGURE 1.5

EFFECT OF FUEL SULFUR CONTENT AND EXCESS AIR ON FLUE GAS ACID DEWPOINT



2.0 PROGRAM BACKGROUND, REQUIREMENTS AND TECHNICAL APPROACH

2.0 PROGRAM BACKGROUND, REQUIREMENTS AND TECHNICAL APPROACH

2.1 Background

As detailed previously in Section 1.0, the technical and economic justification has been well established for the continuous monitoring of stack gas oxygen (O_2) content as a means of quantifying and as an aid for controlling excess air levels employed in boiler combustion processes. This experience has primarily been obtained from the application of continuous monitoring O_2 analyzers to shoreside utility and process boilers and more recently from limited marine boiler installations. While as mentioned in Section 1.0, the eight (8) oxygen analyzers ultimately selected for at-sea endurance testing and evaluation, were zirconium oxide based units, the fifty (50) commercially available units initially screened and evaluated for inclusion in this project ran a wide gamut in terms of basic operating principles and theories.

2.1.1 Redefinition of Program Scope

The initial scope of this program as specified and as contracted included the review and consideration of all types of commercially available oxygen analyzers, regardless of the theory or principle of operation, that had a potential for monitoring oxygen content (excess air) in the exhaust gases of residual oil fired marine boilers. Early on in the conduct of this review it became evident that the current and evolving state-of-the-art for monitoring oxygen content as an indicator of excess air in the exhaust gas from power and process boilers was based on the use of the zirconium oxide coated ceramic cell as a primary sensor supported by high technology electronic signal conditioning and display sub-systems. This basic package was found to be manufactured by a number of different companies and in wide use ashore in numberous utility and industrial applications. The zirconium oxide based analyzer offered a high degree of reliability, compactness, ease of installation and operation and an indication of exhaust gas oxygen content on a continuous basis as determined from contact with users and manufacturers. Finally, there was considerable experience and knowledge in the maritime community concerning the application of wet chemical, electro-chemical, paramagnetic and thermomagnetic systems for oxygen content monitoring in the flue gases of marine boilers. Generally, this experience had been negative.

Taking into account present state-of-the-art systems, ease of installation, and other factors, a decision was made to pursue an evaluation of those commercially available zirconium oxide based oxygen analyzers in generic terms. The remainder of this section presents in detail background, requirements, and the technical approach employed in meeting the program's objectives.

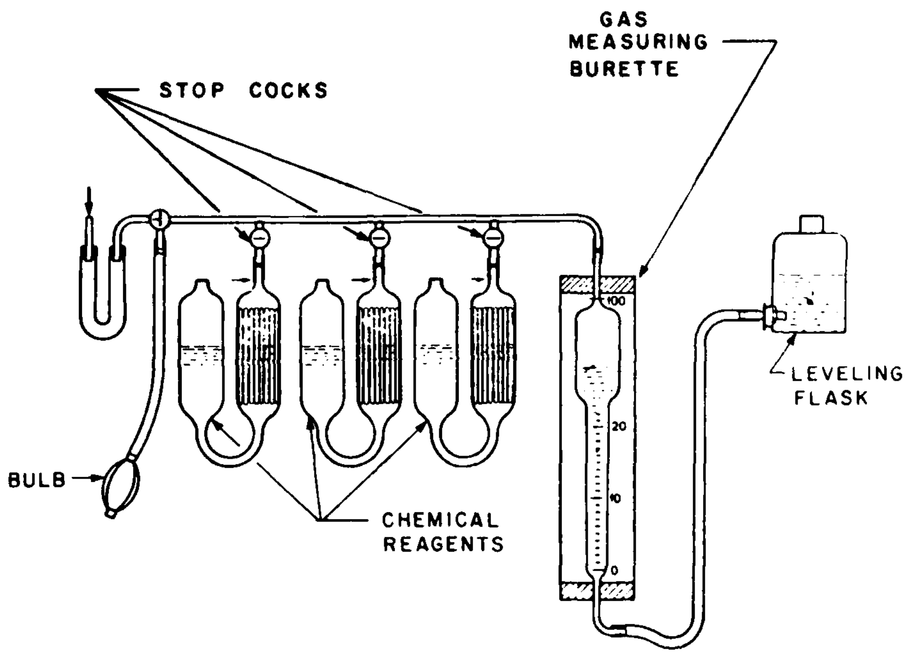
2.1.2 Sensor Types

The O_2 analyzers and analyzer systems reviewed during the selection sub-task of the program can be grouped in the following categories based on their operating principles and theories; wet chemical, electrochemical, paramagnetic, thermomagnetic and zirconium oxide. Other methods for oxygen analysis such as gas chromatography were only briefly investigated and eliminated from consideration due to such factors as delicate design, limited application in such areas as scientific and medical laboratory service and in most instances agreement by manufacturers that these systems were not suited for marine boiler stack gas analysis service. A brief description of the first four (4) types and their typical applications and limitations are presented below followed by a detailed description of the zirconium oxide based principle for sensing oxygen content in the sampled gas. In all cases the content of oxygen in the gas stream is measured on a volumetric basis.

Wet Chemical

Wet chemical analysis of O_2 is based on the exposure of a known volume of gas to chemical reagents. Specific chemical reagents will absorb the different components of the sample gas. By comparing the original and the remaining gas volume, the percentage of oxygen which was present can be quantified. The wet chemical method relies on chemical reagents, measurement hardware, sample filters and piping and an asperator loop. It is a non-continuous spot checking method. In various forms it has been the standard for determining stack gas content and excess air levels in shoreside utility and process boilers as well as marine boilers and many other industrial and scientific applications. Careful care and maintenance of the chemical reagents and asperator loop must be performed on a regular basis to assure accurate reliable results. The active life of the chemical reagents is also very sensitive to cleanliness (unburned hydrocarbon, carbon and sulfur content) of the exhaust gas sample. Figure 2.1 illustrates this apparatus. The final O_2 reading is a gross reading in that none of the oxygen consumed in the chemical process is consumed by or as a result of any other function than determining the sample's O_2 content.

FIGURE 2.1
TYPICAL WET CHEMICAL OXYGEN ANALYZER



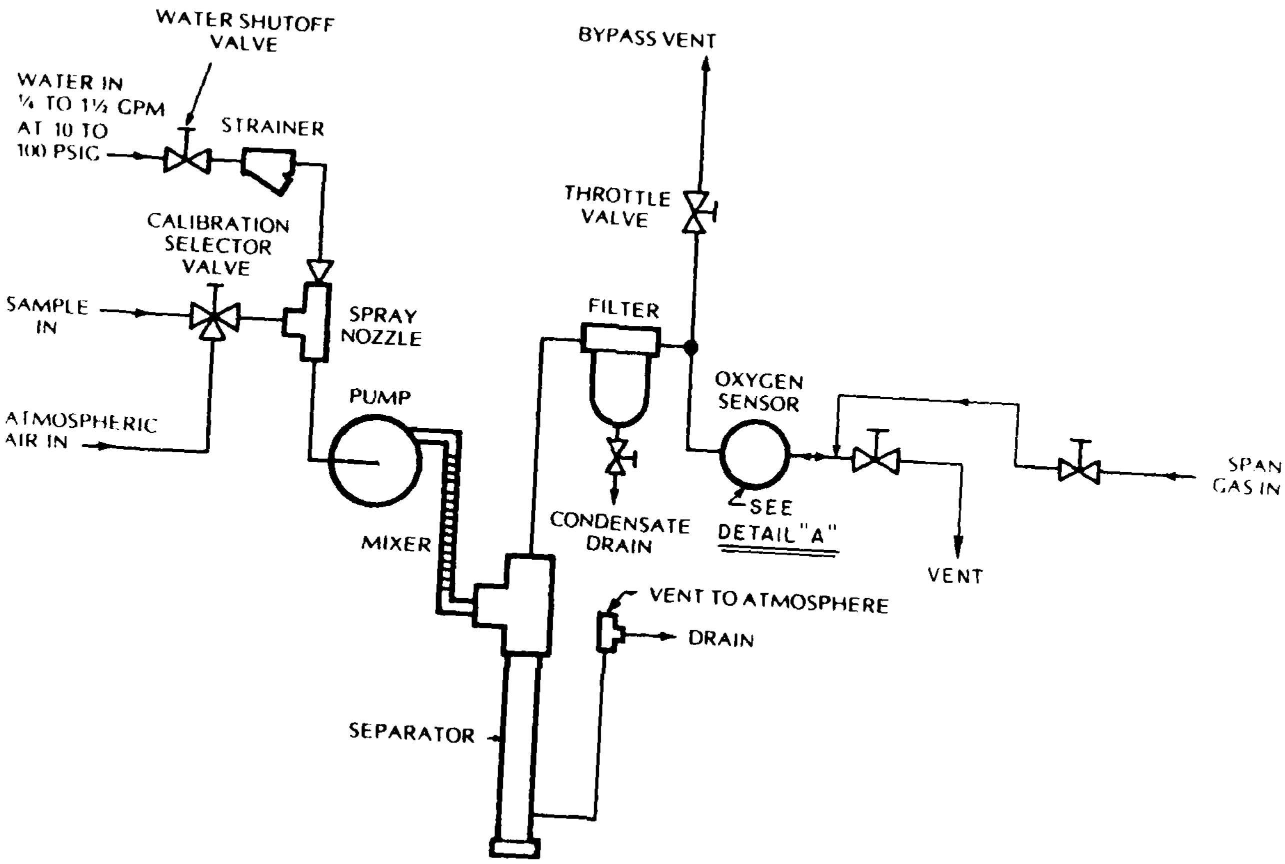
Electro-Chemical

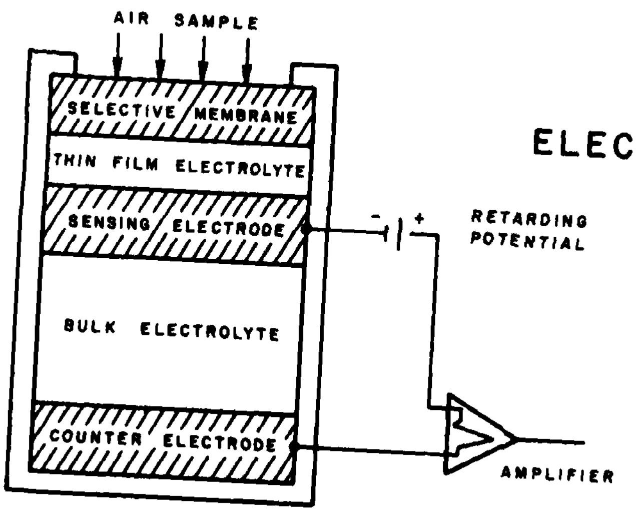
Electro-chemical O_2 analyzers measure oxygen content by forcing the sample through a selective membrane which diffuses the oxygen. This diffused oxygen comes in contact with a cathode/anode array. The reduction of the oxygen at the cathode and oxidation occuring at the annode creates an electrical current which is proportional to the concentration of the oxygen in the gas sample which can then be read on a meter. The electro-chemical system requires a sampling system, sample conditioning (filtering) system, electro-chemical cell and signal conditioning/electronic readout system (see Figure 2.2). O_2 sensors, employing this method may be asembled in a portable system package for spot checks, or complete as a complete sample and conditioning system for permanent installation providing a continuous readout. This system requires maintenance and care similar to that described for the wet chemical method and is also very sensitive to impurities in the sample gas. It also provides a gross analysis of oxygen content. Historically, it has been employed to monitor combustion processes as well as in many other industrial and scientific applications.

Paramagnetic

Paramagnetic analysis of oxygen presence in a sample gas flow employs the principle of oxygen's ability to alter the force of a non-uniform magnetic field. The sample gas is passed through a paramagnetic cell and causes varying effects on the cell's magnetic field depending on the amount of oxygen in the sample. Suspended inside the field is a rotational device which is displaced by the oxygen induced changes in the magnetic field. Typically, a beam of light is made to reflect from this rotational device which is detected by a photo-cell arrangement whereby rotational displacement can be determined and converted into a proportional output signal. The paramagnetic sensor requires a complete sampling system, sample conditioning system and an ambient temperature set point that is maintained continuously in the analyzer. A simplified arrangement is shown in Figure 2.3. In recent years this type of analyzer has seen increased use in combustion exhaust gas monitoring in both shoreside and marine boiler applications. However, it is extremely sensitive to impurities in the sample gas flow and can produce erroneous readings as a result of moderately small build-ups of soot in the cell. Normally these units are supported with effective sample gas filtering devices which must be maintained regularly. Portable units for periodic checks and permanent continuous reading systems are available. These units also produce a gross volumetric measurement of oxygen content.

FIGURE 2.2
TYPICAL ELECTRO-CHEMICAL OXYGEN ANALYZER





DETAIL "A"
ELECTROCHEMICAL CELL

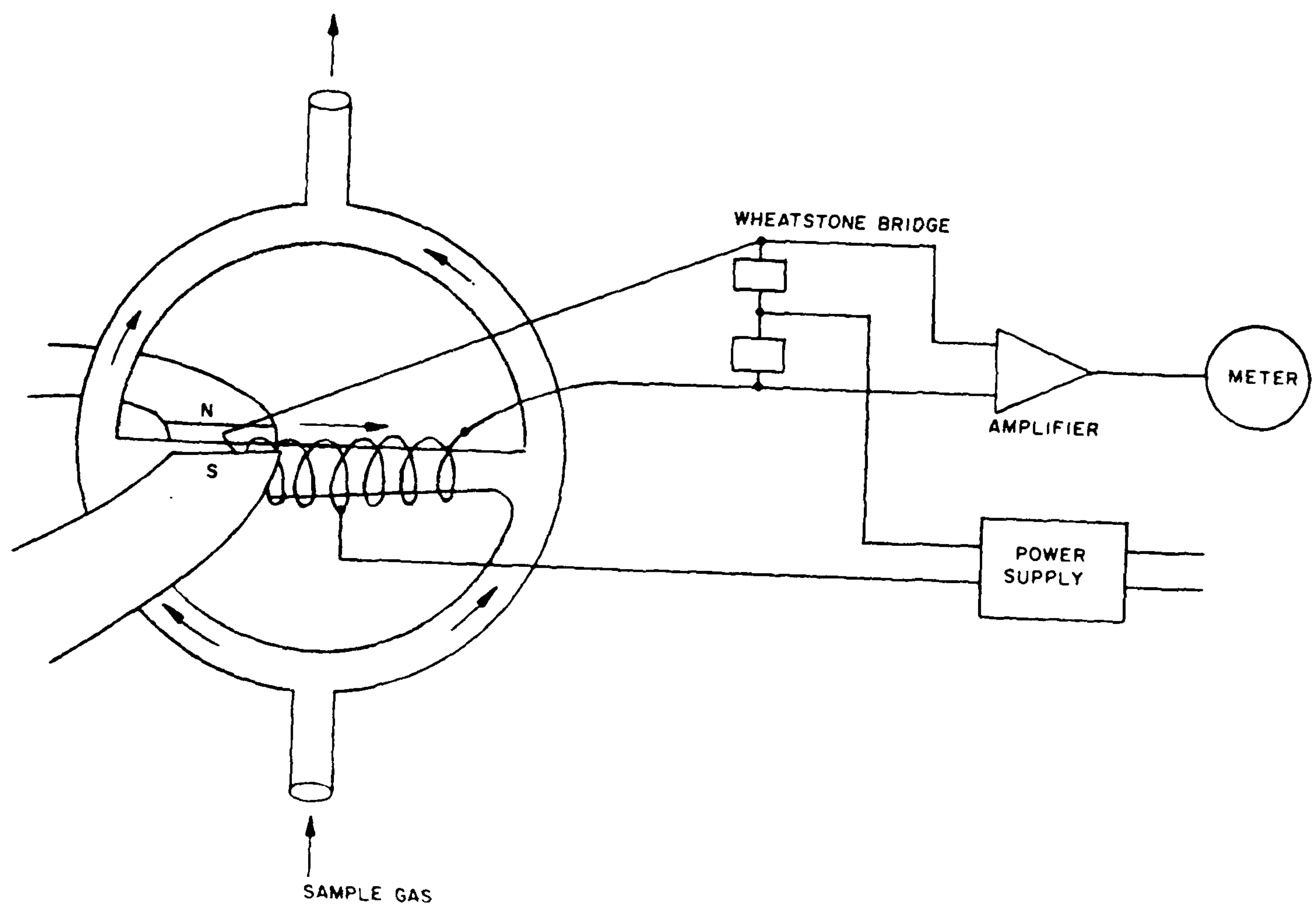


FIGURE 2.3
PARAMAGNETIC OXYGEN ANALYZER

Thermomagnetic

The thermomagnetic analyzer relies upon the paramagnetic properties of oxygen and the effect of temperature on the strength of the cell's magnetic field. By combining a magnetic field gradient and a thermal gradient, it is possible to induce a flow of sample gas through the cell. The intensity of the gas flow is dependent on the concentration of oxygen present in the sample. The oxygen content in the sample gas flow is measured as a result of its effect on the resistance of a temperature sensitive element (thermistor). This thermistor then conditions a constant current signal by means of a Wheatstone bridge circuit which indicates on a meter or other device the oxygen content in the sample. The thermomagnetic system requires a sampling system, a filtering system and a signal conditioning/readout system. A typical sensor is depicted in Figure 2.4. The thermomagnetic based analyzer is sensitive to the same limitations in terms of sample gas cleanliness as the paramagnetic device, produces a gross volumetric reading of oxygen content and can be provided in a portable or continuous on-stream configuration.

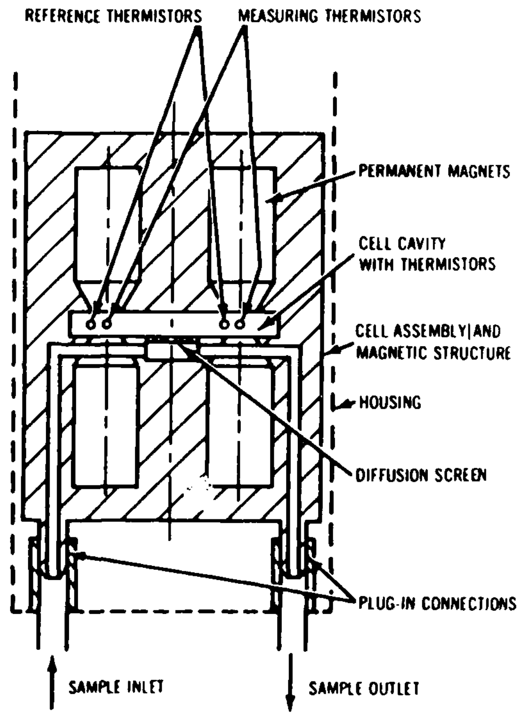
Zirconium Oxide

Zirconium oxide is a material that, when heated, becomes permeable to oxygen ions. When the zirconium oxide coated ceramic cell is exposed to flue gas on one side and reference air on the other it acts like a solid electrolyte. The greater the difference in oxygen concentrations on either side (or partial pressures of oxygen), the higher the voltage potential generated across the cell. This voltage potential across the zirconium oxide coated cell is detected by (+/-) electrodes as a cell output signal which is conditioned by the analyzer solid state electronics and displayed as a percent by volume oxygen concentration.

The predictability of zirconium oxide's response to the partial pressure of oxygen is defined by the Nernst Equation. The Nernst Equation, simply stated, is the relationship which defines the voltage potential developed across the heated surfaces of the cell when exposed on each side to different concentrations of oxygen. This equation was employed in all of the analyzers tested. The relationship between the cell output, temperature, cell constant and the sample and reference oxygen concentrations can be expressed by the following equations:

$$E = \frac{RT}{4F} \text{Ln} \frac{(P1)}{(P2)} + C$$

FIGURE 2.4
THERMOMAGNETIC OXYGEN ANALYZER SENSOR



Cross-Section of Sensing Unit

E = Output Voltage of Cell

R = Gas Constant

F = Faraday's Constant

T = Temperature of Cell (absolute)

P1 = Partial Pressure of Oxygen (reference gas, air)

P2 = Partial Pressure of Oxygen (sample gas)

C = Cell Constant

or stated differently:

$$E = KT \log_{10} \frac{P(R)}{P(S)} + C$$

E = Output Cell Voltage

K = Constant Involving the Gas Constant and Faraday's Constant

T = Absolute Cell Temperature in $^{\circ}$Kelvin

P(R) = Partial Pressure Oxygen (reference gas, air)

P(S) = Partial Pressure Oxygen (sample gas)

C = Cell Constant

Using the Nerst Equation, the manufacturer first determines the cell constant which is different for each zirconium oxide coated cell. After the cell constant is computed, the only other variables in the equation become the temperature and the unknown quantity or partial pressure of oxygen in the sample gas, the gas constant, Faraday's Constant and the partial pressure of oxygen in the reference gas (air) being defined quantities. Since the temperature range at which zirconium oxide reacts according to the Nernst Equation is between 1100 and 1500^{o}F, the manufacturer may provide elements and circuitry to heat and maintain the cell at an elevated constant temperature in this range. In this manner the cell temperature portion of the equation also becomes a constant. If the temperature is not held constant, the accuracy and calibration of the analyzer will drift. The other alternative is to include additional analyzer electronics which solve the Nernst Equation for P(S) and T continuously. This important relationship of cell output voltage and temperature is depicted in Figure 2.5.

The zirconium oxide analyzers for the purposes of this program were selected based primarily on their strong points of suitability for marine service (dirty gas), minimal support systems required, flexibility of location, method of sampling (direct, continuous) and shoreside and marine user operational and maintenance experience. The output of the device in percent oxygen by volume is considered to be a net reading. This is due to the fact that any unburned hydrocarbon vapors or soot entrained in the sample will tend to combust in the cell at elevated temperatures (1100 to 1500^{o}F). This combustion tends to reduce or deplete the oxygen in the sample resulting in a "net" reading across the cell. This effect is felt to be very minimal throughout the operating range of a typical marine boiler except in transient, upset conditions where soot and/or unburned hydrocarbons may be present such as during maneuvering or soot blowing.

A major sub-category among the zirconium oxide analyzers was the method of sampling, extractive versus in-situ.

Extractive zirconium oxide analyzers are those units where the zirconium oxide coated cell is located adjacent to but outside of the flue gas path, and an eductive air loop is used to flow flue gases past the cell. The in-situ zirconium oxide analyzers are those units where the zircinium oxide coated cell is located directly in the gas path and needs no air eductor to flow flue gases past the cell. A balance was sought between the number of in-situ and extractive type units tested. The final selection for testing included four (4) in-situ analyzers, three (3) extractive analyzers, and one (1) combination in-situ extractive analyzer that had the cell in the gas path but required an air eductor flow to pull flue gas past the cell. Figures 2.6 and 2.7 depict typical zirconium oxide oxygen analyzer extractive and in-situ primary sensor configurations.

2.2 Development of Test Requirements and Methodology

Test requirements and methodology were identified and developed prior

FIGURE 2.5
CELL VOLTAGE vs OXYGEN CONCENTRATION AT VARIOUS CELL TEMPERATURES

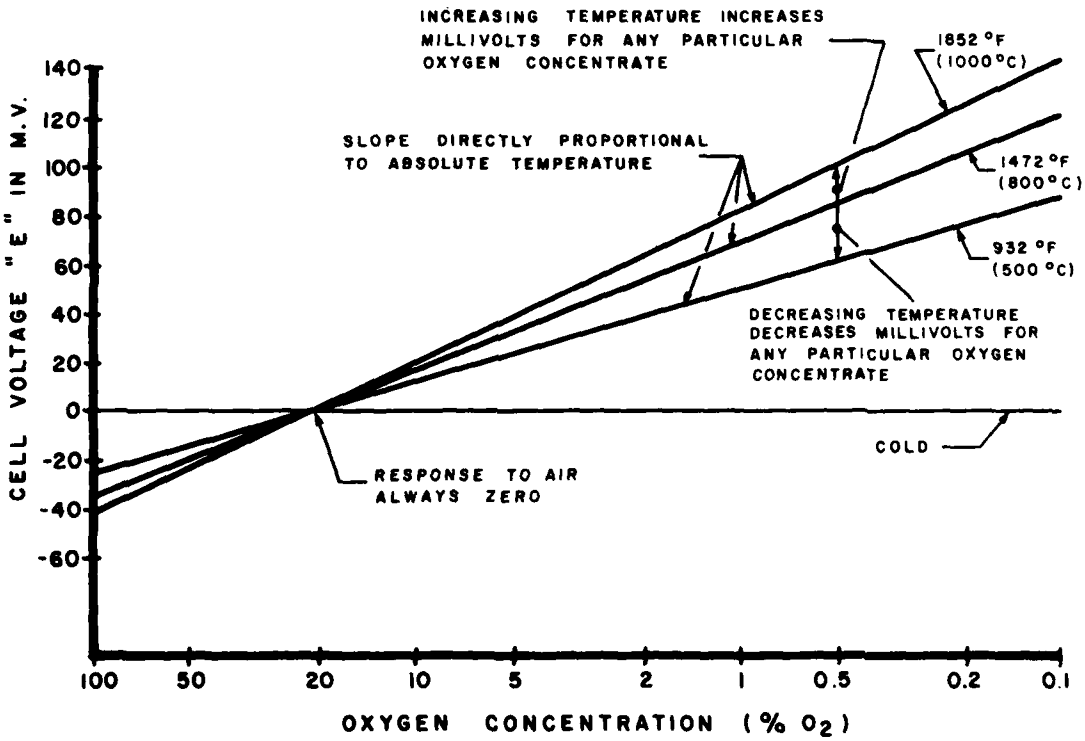


FIGURE 2.6
TYPICAL EXTRACTIVE TYPE ZIRCONIUM OXIDE O_2 ANALYZER SENSOR CONFIGURATION

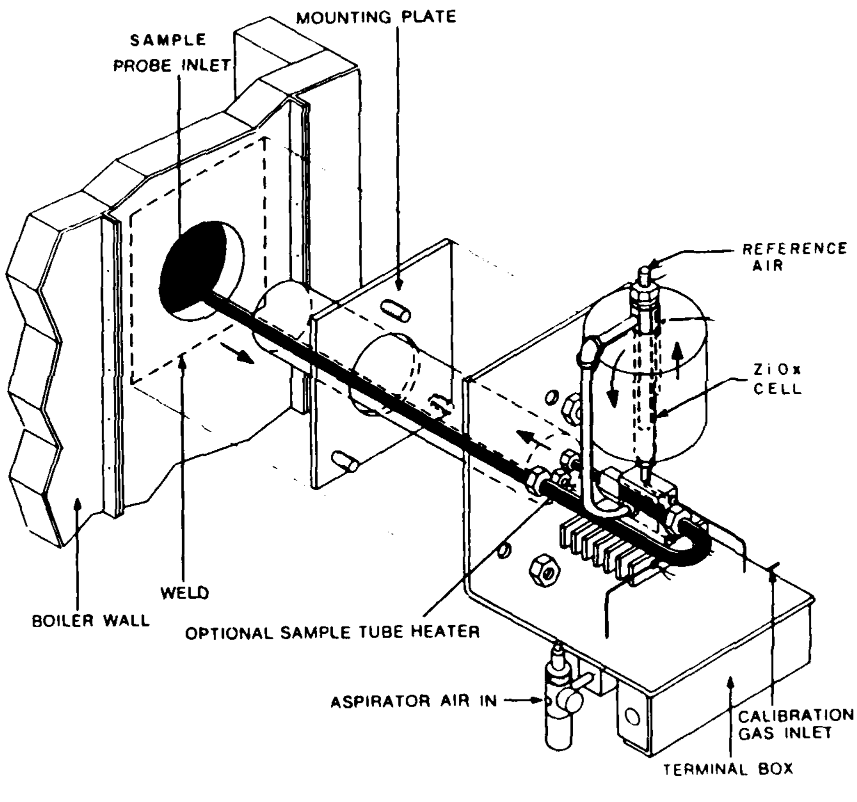
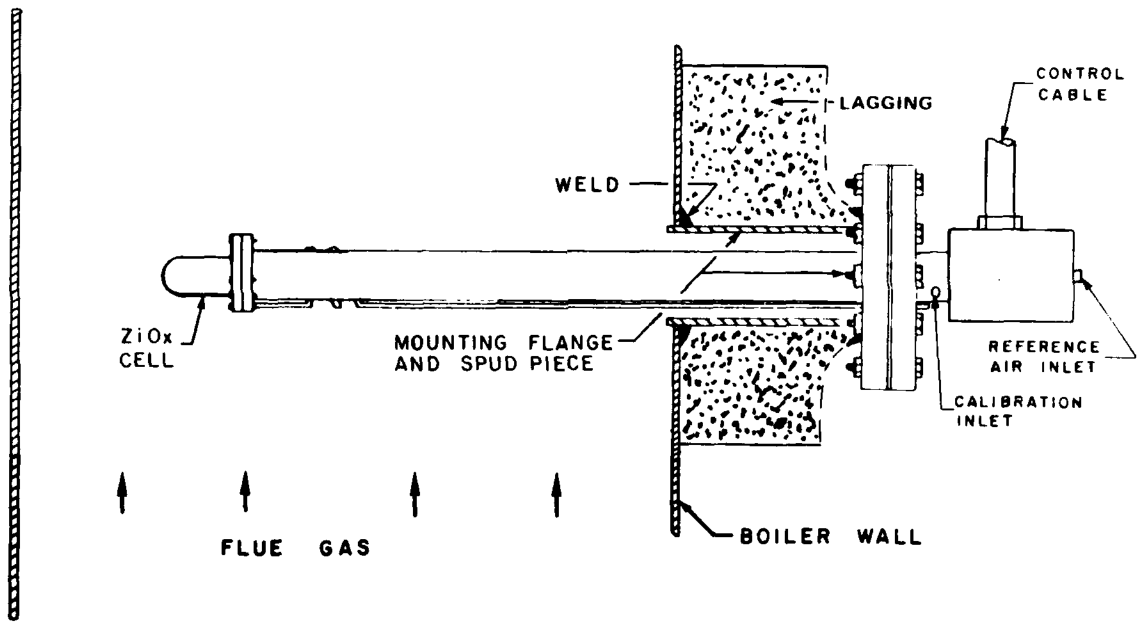


FIGURE 2.7
TYPICAL IN-SITU TYPE ZIRCONIUM OXIDE O_2 ANALYZER SENSOR CONFIGURATION



to the final selection, installation and endurance testing of those commercially available oxygen analyzers initially screened as potentially suited for marine service. This work ultimately shaped and defined the overall technical approach and assured that the necessary qualitative and quantitiative data required from the at-sea endurance testing program phase would be obtained in sufficient detail and quantity so as to meet the program's objectives. This effort is described in the following paragraphs.

2.2.1 Test Vessel and Boiler Selection

The at-sea operational endurance testing was felt to be the heart of the program as the ambient engine room conditions under which the oxygen analyzers were to be evaluated would reflect shipboard conditions that are considerably more deleterious to typical monitoring instrumentation than those present in a more controlled and stable industrial or utility boiler application. Some of the more severe marine power plant environmental factors and conditions typically encountered are listed below.

* 30° roll side to side; 15 second period (full cycle)
* 6° pitch bow-up to bow-down; 6 second period (full cycle)
* 15° list either side
* 3° trim either by bow or stern
* Continuous exposure to moisture, corrosive, abrasive and/or salt laden atmospheres
* Ambient air temperatures of up to $122^{\circ}F$ ($50^{\circ}C$)
* Extremes in operating cycles and conditions including frequent on/off operation and random preventative maintenance
* Electrical power generation and distribution system instability including poor wave form and unbalanced voltage
* Exposure to abnormal shock and vibration

Test Vessel

Working with the operator, Lykes Brothers Steamship Company, Inc., of New Orleans, Louisiana, a general cargo vessel from their "Far East Clipper" class, the S. S. STELLA LYKES, was selected to serve as the test vehicle. Delivered in 1966, she is 540 feet long overall and is powered by a cross-compound, geared marine steam turbine engine developing 15,500 shaft horsepower producing a speed of 20 knots at a maximum displacement of 21,840 long tons. The vessel is depicted underway in Figure 2.8. During the term of the at-sea O_2 analyzer endurance testing she was operated in both the U. S. Gulf/Mediterranean and U. S. Gulf/Far East trades.

Boilers

The vessel is fitted with two (2) watertube, double cased, oil fired steam generators equipped with steam air heaters and economizers. The oil fired in the boiler is Bunker C, a residual fuel common to most marine steam power plants. The steam atomized oil burners in each boiler are designed to provide total combustion with 15% excess air or 15% more air than is required for complete (stochiometric) combustion of the fired fuel. This correlated to a normal at-sea condition of three percent (3%) oxygen content by volume in the flue gases. Throughout the test duration the vessel was operated consistently within the 12,000 to 13,000 SHP range. The boiler manufacturer consequently confirmed that this would equate to approximately 80 to 85% of rated boiler load and that operation with 15% excess air could be anticipated. Figure 2.9 presents as designed performance data for the installed boilers.

Sensor Locations

The location on the boiler at which the analyzers would sample the flue gas was an important consideration. Ideally the best arrangement would allow for all of the analyzers to draw from a single point on the boiler as close to the point of combustion as possible. However, various constraints and factors peculiar to the temporary test nature of the project resulted in some compromise of the ideal sampling location. These are listed briefly below.

* The eight (8) analyzers to be tested, some extractive and some in-situ, could not physically sample from a single point on the boiler and function properly.

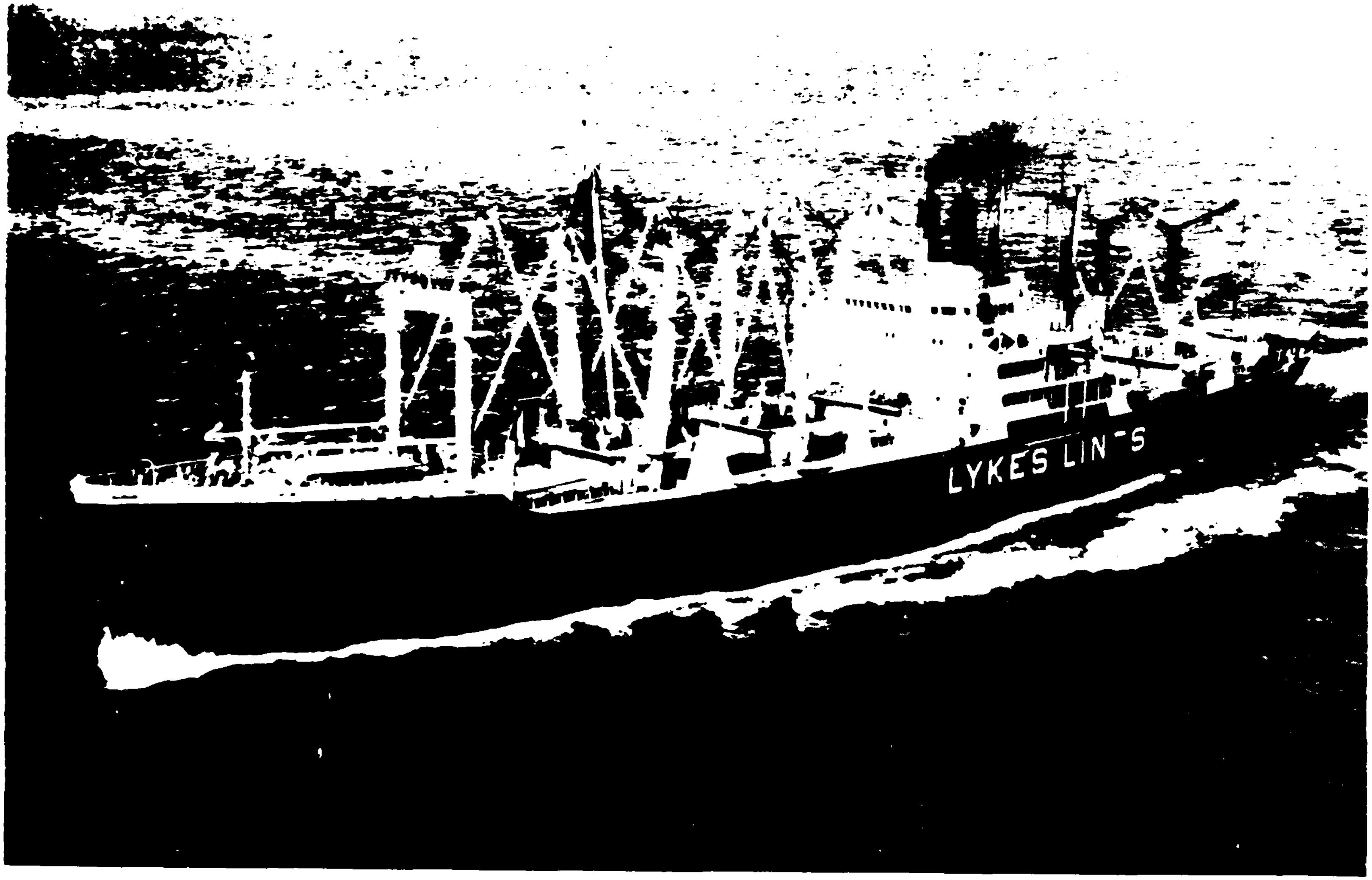
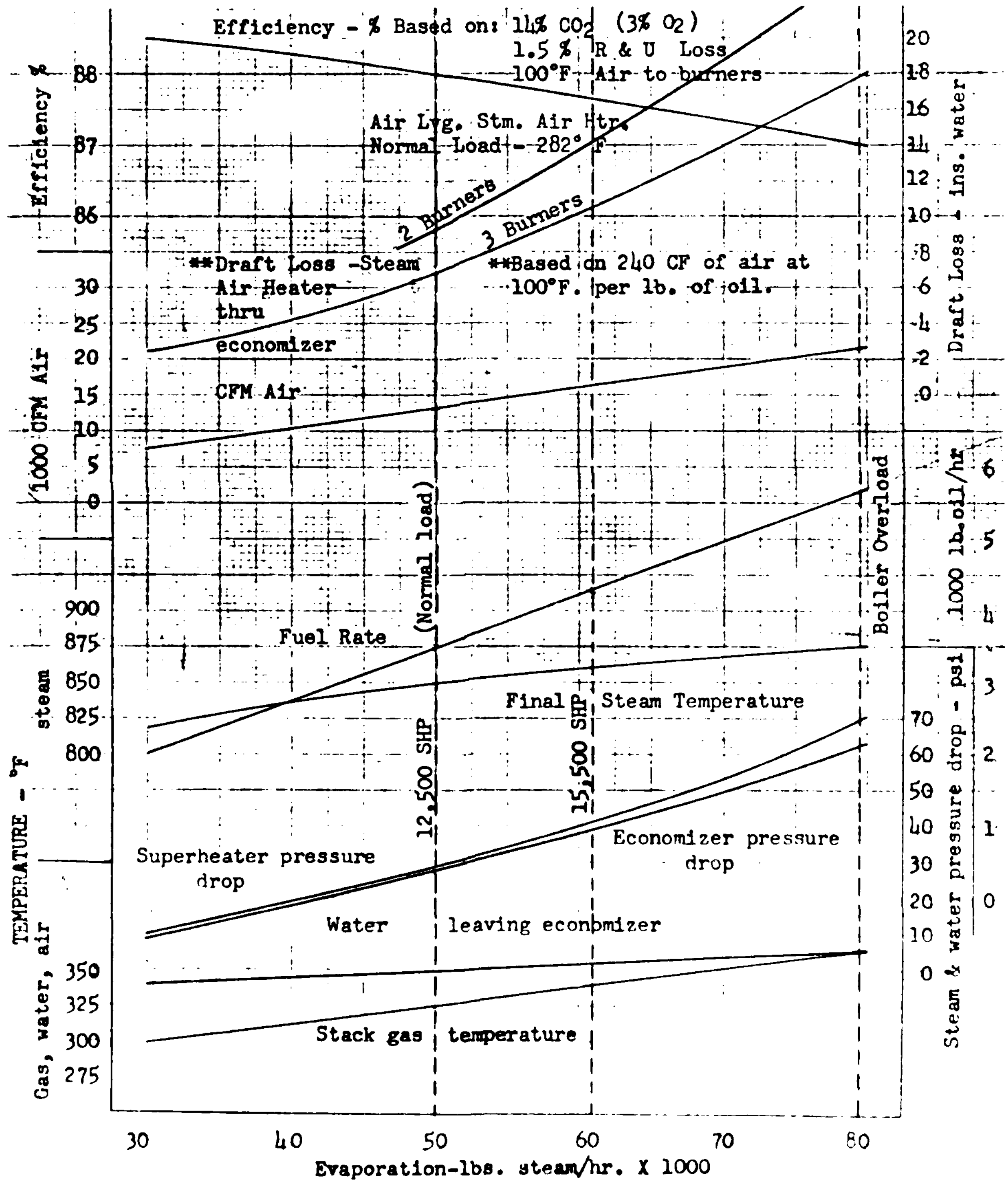


FIGURE 2.8
TEST VESSEL, S.S. STELLA LYKES

FIGURE 2.9
TEST BOILER DESIGN PERFORMANCE DATA

Operating Data		Boiler Data
600 psi	@ SH Outlet	Boiler HS 5310 sq.ft.
850°F	@ SH Outlet	Waterwall HS 905 sq.ft.
278°F	Feedwater *	Economizer HS 5040 sq.ft.
100°F	Air(Ambient)	Total HS 11255 sq.ft.
		Furnace Volume 1035 cu.ft.



* The final number of analyzers tested (8) required that both boilers be employed due to physical space requirements for each analyzer.

* Installation of the sensors for each analyzer as close to the furnace as possible would require penetration of first the outer casing, insulation and perhaps even reconfiguration of tubes in the boiler side walls surrounding the furnace. This would have been time consuming and expensive and was deemed unacceptable, due to the temporary nature of the installation and its potential difficulties, by the operator.

The final locations selected on each boiler for sensor installation were in the single cased uptakes just above the economizers. This location was well within the installation recommendations of each analyzer manufacturer and allowed for ease of access for installation, service and monitoring. In addition, they would also be installed at a level in the engine room that enhanced and optimized the at-sea test and evaluation phase's continuous data recording system configuration while offering minimal interference with the normal day-to-day boiler operating and maintenance requirements. These locations were also approved by the operator. The above locations were initially considered preliminary and allowed for the layout and arrangement of the shipboard long-term automatic data recording system and for identifying additional installation requirements. Upon final selection of the eight (8) analyzers ultimately evaluated, these locations were again reviewed and retained as final sensor sampling points.

2.2.2 Test Duration

In order to accomplish the stated objectives of the program an at-sea test and evaluation period of ten (10) months of continuous operation and data gathering for the eight (8) analyzers evaluated was considered to be the maximum practically achievable within the scheduled eighteen (18) month duration of the program. The analyzers were installed and the at-sea test and evaluation phase of the program conducted almost continuously from April, 1980 through January, 1981. Approximately two (2) weeks of data gathering time were lost during this period due to temporary layups and shipyard repair periods.

All tasks associated with the program requiring interface with the test vessel including initial analyzer installation, extended at-sea endurance testing and data gathering and rip-out and vessel restoration were planned and carried out on a no delay to the vessel basis. At no time during the test duration did the accomplishment of these tasks cause any disruption to the normal power plant operating routine or place what could be considered an unreasonable burden on the operating crew in terms of additional work load.

2.2.3 Data Requirements and Evaluation Criteria

As stated in the introduction, the nature of the at-sea test and evaluation of the eight (8) commercially available zirconium oxide oxygen analyzers was that of a long-term endurance run. The intent of this evaluation was to identify and document the strengths and weakness of each machine as it operated in a typical shipboard environment. The data types required for this evaluation are described below.

2.2.3.1 Quantitative Data

(1) Continuous Automatic Data Recording throughout the at-sea test period. The oxygen reading displayed by each unit was logged automatically and continuously by means of interface with a strip chart recorder.

The two (2) strip chart recorders were equipped with four (4) current modules and pen servos each. All of the analyzers' output signals (% O_2 signals) from the port boiler were recorded on one strip chart and four outputs of the analyzers in the starboard boiler were recorded on the other strip chart. The individual channels of each strip chart recorder were calibrated for a 0-100% full scale travel, left to right, for a 4-20 ma signal. The chart speed for each recorder was set at four (4) cm per hour. The strip chart pen servos were protected from over travel by mini-breakers which would limit pen movement at the extreme ends of the scale. Signal print overlay was reduced by stacking the print pens at a 1 mm offset between pens. Different colored print pens were used in each channel of the recorders for ease in identifying each unit's track. The strip chart recorders were housed in a specially modified NEMA-4 utility enclosure. The door of the enclosure was fitted with windows, so that visual inspections could be made. The enclosures were locked for the duration of the test, except for the renewal of paper and pens. Figure 2.10 presents a schematic of wiring and interface requirements for the continuous automatic data logging system.

(2) Manually Logged Data. Manually logged data requirements were developed consistent with the operator's desire to place as small an additional labor burden as possible on ship's engineering force. The data to be recorded manually consisted mostly of boiler performance data. This information was felt to be necessary in order to differentiate between changes or drifts in continuously recorded analyzer % O_2 readings that could result from analyzer component failures or problems and changes in recorded O_2 levels resulting from such factors as increase or reduction in boiler steaming load or forced fan speed or inlet damper position. In addition, the % O_2 indicated on each analyzer was also logged. This information was recorded daily at noon. The log sheet developed and employed is illustrated in Figure 2.11.

The responsibility for data logging and monitoring and support of the test apparatus and system (i.e., renewing strip chart recorder paper and pens) was assigned to the Chief Engineer who inturn delegated these duties under his close supervision and scrutiny to the U. S. Merchant Marine Academy Engine Cadet assigned to the vessel throughout the test period.

(3) Service Files. A service file was maintained by the contractor for each analyzer which contained a detailed record of all adjustments, failure analyses, part renewals, technical services, fees and associated information from receipt of the analyzers through the test period up until rip-out and termination of the program. All service oriented tasks associated with required repairs to each analyzer were performed only by authorized factory or service representatives.

(4) Calibration Check Records. Each analyzer was manufactured with a means for calibration checking and recalibrating, if required. The calibration of each machine was checked periodically throughout the at-sea test and evaluation period to establish any trends of calibration shift for each machine while working in a typical shipboard environment. Recalibration, when required, was to be performed by authorized factory or service representatives.

The oxygen analyzers were calibration checked at the following times.

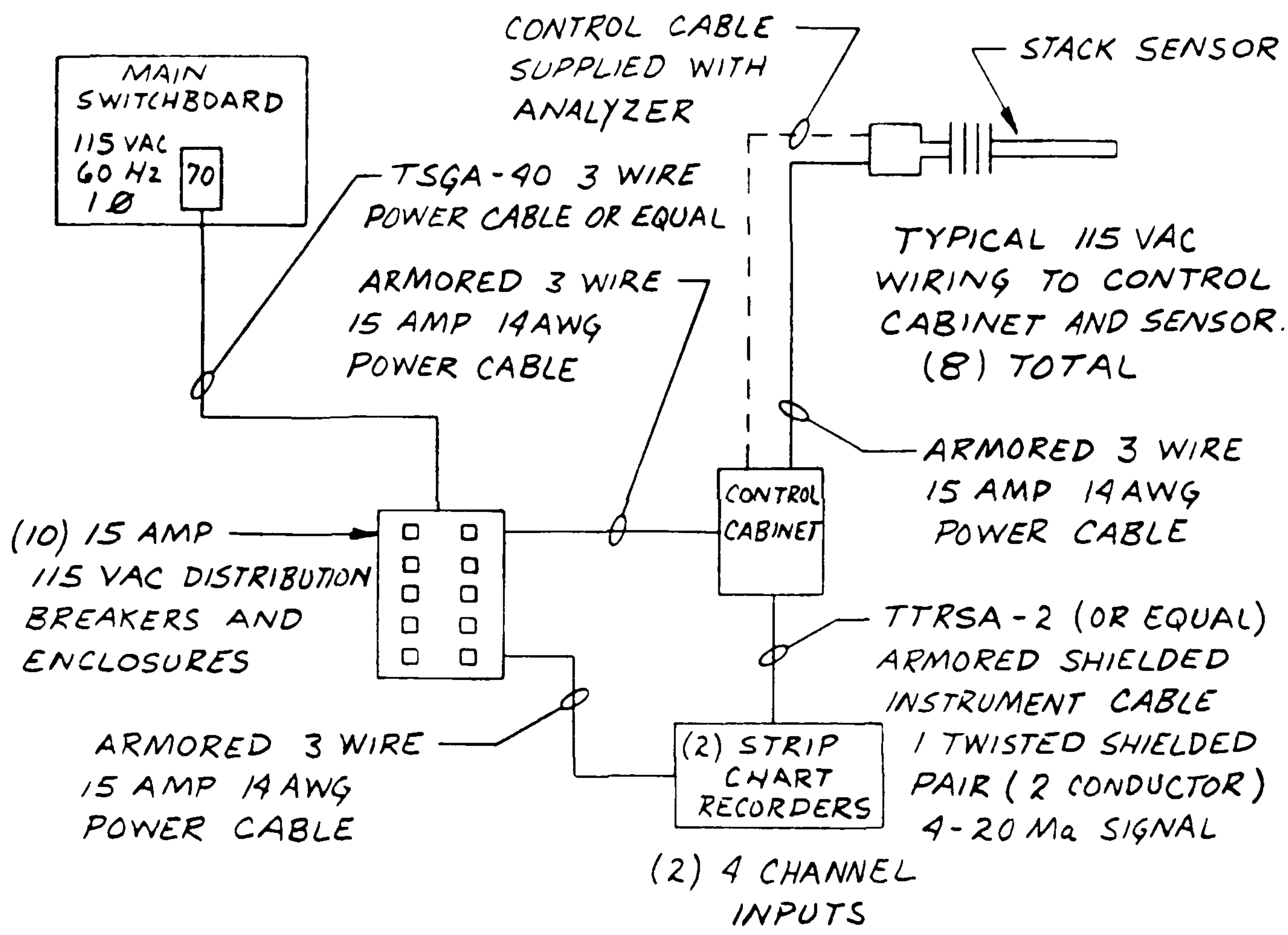


FIGURE 2.10
AUTOMATIC DATA LOGGING SYSTEM WIRING AND INTERFACE SCHEMATIC

Date ____________________

Ship Data Log Sheet

Voyage No. ______________

DAILY LOG

1) Red Analyzer % 0_2 ____________ Comments:

2) Green Analyzer % 0_2 ____________

3) Orange Analyzer % 0_2 ____________

4) Blue Analyzer % 0_2 ____________

5) Gold Analyzer % 0_2 ____________

6) White Analyzer % 0_2 ____________

7) Black Analyzer % 0_2 ____________

8) Yellow Analyzer % 0_2 ____________

9) Port Boiler #Burners Lit ______________ Tubes Blown ____________ Hrs.

10) Stbd. Boiler #Burners Lit ______________ Tubes Blown ____________ Hrs.

11) Engine Room Operations: (Log times in each mode)

Underway _________ Hrs. Manuevering _________ Hrs. Port ___________ Hrs.

12) Engine Room Temp. @ Console ____________ ^{o}F.

13) Engine Room Temp. @ Uptakes ____________ ^{o}F.

14) Air Temp. to Burners Port _________ ^{o}F. Stbd _____________ ^{o}F.

15) Uptake Temp. Port _________ ^{o}F. Stbd _____________ ^{o}F.

16) Windbox Press Port _________ "H_2O Stbd _____________ "H_2O

17) Furnace Press Port _________ "H_2O Stbd _____________ "H_2O

18) Economizer Outlet Press Port ________ "H_2O Stbd _____________ "H_2O

FIGURE 2.11
SAMPLE LOG SHEET FOR MANUALLY LOGGED DATA

* At factory prior to shipment

* Initial shipboard (at installation) start-up

* End of first voyage

* End of second voyage

* End of third voyage (prior to rip-out)

In all cases the 2 and 3% oxygen in nitrogen background calibration gas were used to check the zero and the 10, 15 and 20.9% (air) were used to check span. The long-term drift was recorded as a function of the change from start-up calibration check readings. Calibration check consistency was enhanced by utilizing the same bottles of calibration gases throughout the test. Manufacturer's directions were followed judiciously with regard to calibration gas flow rates, pressure, etc., so that the most accurate calibration check readings were obtained.

Generally, the in-situ type analyzers were equipped with a more complete calibration sub-system that made calibration checking quite simple and fast. The extraction type analyzers additionally required more support systems such as external tubing, pressure reducers, valving and flow regulators that made calibration of these units in some instances very cumbersome. Figures 2.12 and 2.13 present typical calibration arrangements for in-situ and extractive type analyzers.

(5) Timed Tests. As additional comparative data various timed responses were recorded for each analyzer after initial installation and prior to rip-out after completion of the ten (10) month at-sea endurance testing.

Warm-Up: The length of time a unit required to obtain a final steady state value from a cold start-up condition.

Response Time: The length of time a unit required to reach 90% of the final steady state value after a step change in concentration of a known quantity (calibration gas) is introduced.

(6) Wet Chemical Readings. Oxygen readings utilizing an orsat

FIGURE 2.12
TYPICAL CALIBRATION ARRANGEMENT FOR AN IN-SITU ANALYZER

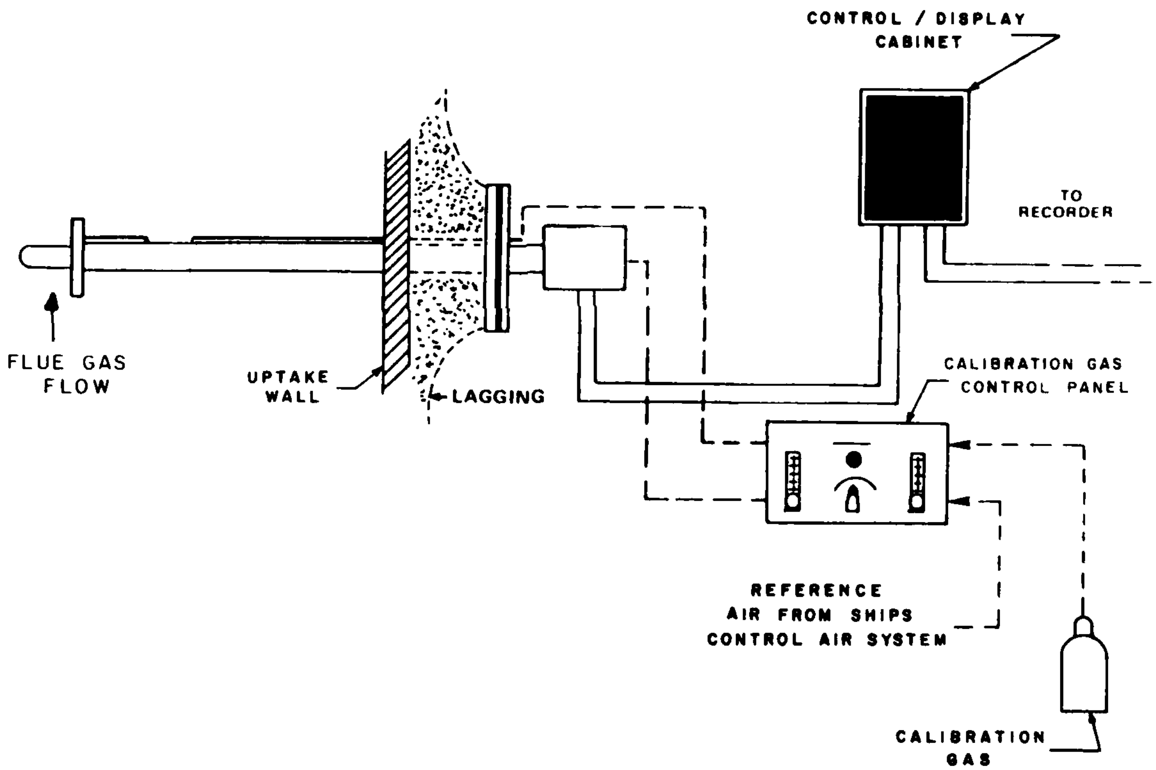
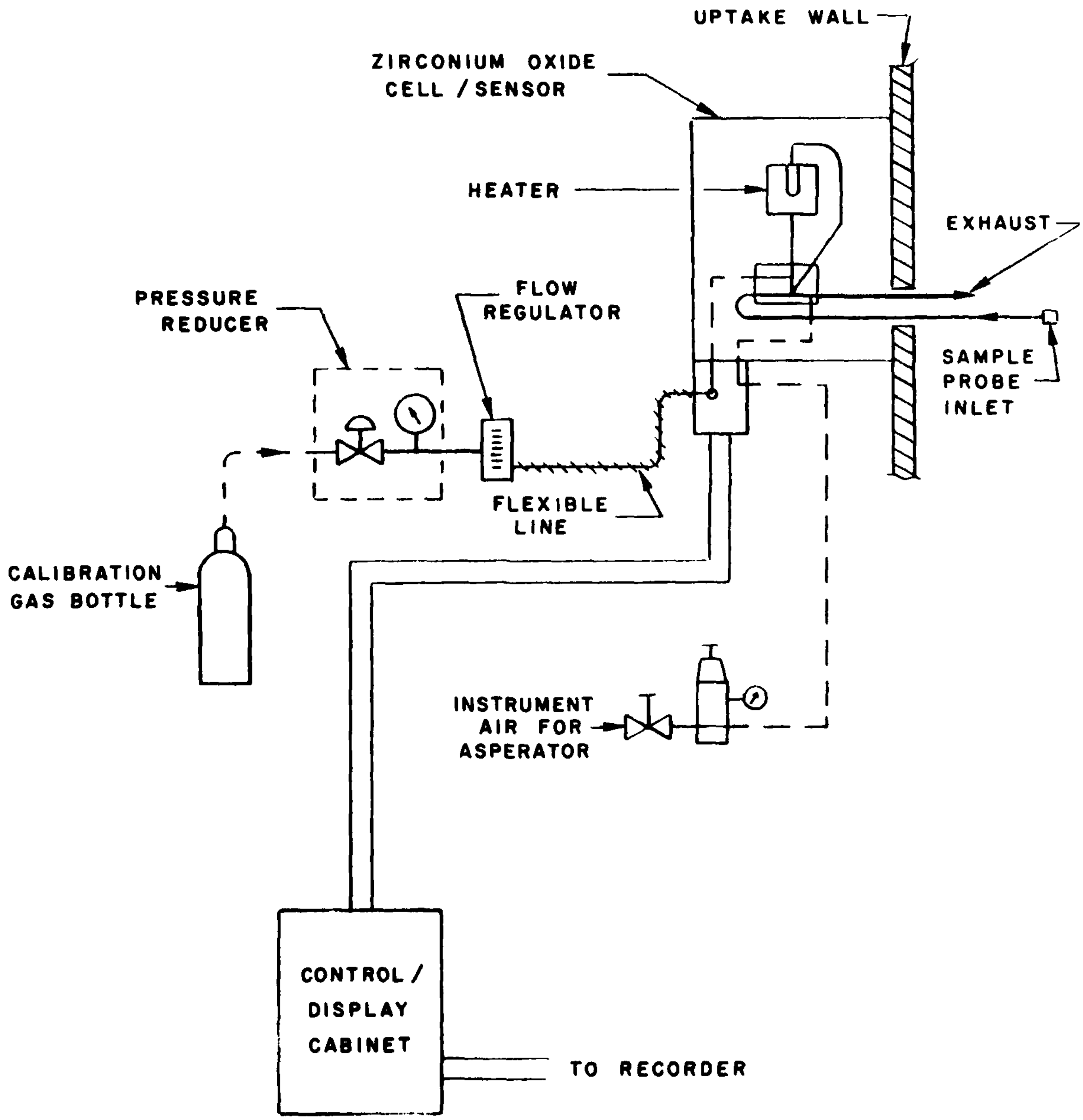


FIGURE 2.13
A TYPICAL CALIBRATION ARRANGEMENT FOR AN EXTRACTIVE ANALYZER



system were taken once daily during the evaluation by the ship's operating personnel and recorded as supplementary data.

2.2.3.2 Qualitative Data

Throughout the course of the program numerous observations of a qualitative nature were made by contractor, shipping company shore staff and shipboard operating personnel concerning various aspects, features and drawbacks associated with each analyzer. These comments were recorded on and/or obtained from such sources as the daily log sheets for manually logged data, voyage letters, during informal crew debriefings which were held at the end of each voyage during the at-sea endurance testing and from repair and service reports. A formal questionnaire was also developed (see Appendix A) that provided a large body of information from the shipping company's shore staff and shipboard operating crew concerning their preferences and dislikes for the various features associated with each analyzer. While this information in some instances tended to be subjective in nature it nonetheless provided considerable insight when compiling the recommended specification for a marininized zirconium oxide based contintuous reading oxygen analyzer.

The following is a partial listing of typical topics and items which were qualitatively addressed, analyzed and scrutinized.

* Installation requirements
* Support requirements (power, air, etc.)
* Ease of operation
* Calibration requirements and procedures
* Troubleshooting guides/self diagnostic features
* Quality, usefulness and ease of interpretation of operating/instruction manuals
* Spare parts requirements
* Quality of piping, wiring and printed circuit board (PCB) schematics
* Completeness of analyzer as shipped for installation

* Display, alarm, set point, etc., features

2.2.4 Test Standards

The standard selected for periodic checks of changes in analyzer calibration was calibration gas. The calibration gases were mixtures of a known quantity oxygen in a background of inert nitrogen. These gases were provided and certified by a specialty gas company. Each calibration gas standard had an analytical accuracy guaranteed to within $\pm$ 2% of the certified oxygen concentration. Concentrati[illegible] selected for the program were:

* 2.0% oxygen; balance nitrogen
* 3.0% oxygen; balance nitrogen
* 10.0% oxygen; balance nitrogen
* 15.3% oxygen; balance nitrogen

2.2.5 Maintenance and Repair Guidelines

Because of a general lack of familiarity that the typical shipboard operating crews were expected to have with the design, operation and maintenance and repair aspects of typical zirconium oxide based oxygen analyzers, it was decided that all required maintenance and repair actions resulting from a failure or malfunction of the analyzers during the at-sea endurance testing phase were to be conducted by authorized factory or service representatives, only. In addition, it was felt that this decision also ensured that no analyzer's performance during the test would be affected or prejudiced by imprudent or incorrect maintenance or repair procedures carried out by any personnel, including contractor personnel, who were not completely familiar and qualified to perform the required repair actions. Based on this approach, a machine that failed at-sea during one of the three voyages that comprised the endurance test period was left in that condition until return of the vessel to the U. S. Gulf Coast where it was restored to operation by an authorized manufacturers representative under the close supervision of contractor and operator program personnel. Further, to assure than no unauthorized tampering of the analyzer electronics would occur during the at-sea endurance testing, each unit was sealed at the time of initial start-up and calibration checking by trained and authorized service representatives and subsequently thereafter on each occasion when repairs due to failure were required. The Chief Engineer on the vessel witnessed the sealing of each unit. Appendix B contains a copy of the initial certification letter from the Chief Engineer.

While this decision precluded the shipboard operating crew from performing any analyzer internal electronics maintenance and repair, they did perform certain routine maintenance actions such as blowdown of asperator and/or reference air supply filters and moisture extractors and air pressure regulator pressure setting and adjustment. These tasks were carried out primarily by the Chief Engineer and the Engine Cadet.

2.2.6 Evaluation Criteria

The eight (8) commercially available oxygen analyzers selected for the at-sea endurance test phase were evaluated on a quantitative and qualitative basis employing the criteria listed and defined (as they pertained to this specific program) below. These criteria were applied to each analyzer on an individual basis and were not intended for use as a direct comparative basis for analyzer performance, one versus the others. Utilizing these factors and the test data associated with each one, a composite of optimum features for a marinized version of a zirconium oxide based oxygen analyzer was developed resulting in the production of a recommended specification for these devices.

<u>In-Service Performance:</u> The in-service performance characteristics and criteria as determined for this program consisted of the following:

(1) Ability to operate continuously

(2) Ability to operate unattended

(3) Response and sensitivity to changes in the sampled gas concentration

(4) Ability to produce accurate, stable readings

<u>Repeatability:</u> The closeness with which an analyzer was able to produce the same indication of the measured variable (% oxygen content) under steady state conditions on a continuous or repetative basis.

Calibration and Calibration Requirements: The checking of analyzer output throughout its operating range by introducing known and certified values (calibration gas) of the measured variable to determine the error (and required correction) while keeping all other process variables constant and the required frequency of and complexity involved in calibration checking and recalibration.

Maintainability: The frequency and complexity of routine maintenance actions required to be performed to keep an analyzer operating at its optimum level of performance. In addition, under this category support and installation requirements including electrical power, control (compressed) air, auxiliary steam or cooling water and sootblowing asperator or reference air loop protective provisions were also considered.

Repairability: The complexity, difficulty and time required to perform repairs associated with a random failure of a unit as determined from actual failures during the endurance test and/or as a result of a detailed review of such features as analyzer design, instruction manuals, troubleshooting guidelines, system schematics and if provided, self diagnostic features.

Environmental Influences: The ability of an analyzer to function in the more severe marine environment as described previously in Section 2. 2. 1.

2. 3 Technical Approach

The technical approach taken to successfully accomplish the stated objectives of the program was that of a time phased program consisting of five (5) discrete program tasks. Figure 2. 14 presents the chronological organization of each project task and sub-task. The following description of the technical approach taken is divided into three (3) distinct categories and is described in the following paragraphs.

2. 3. 1 Analyzer Selection

The final selection and procurement of the eight (8) oxygen (O_2) analyzers tested was preceded by a thorough survey of manufacturers of oxygen analyzers of all sensor types and applications. Buyer guides, product registers, and numerous periodicals were reviewed to identify manufacturers of oxygen analyzing equipment. Two (2) series of questionnaires were mailed to all prospective suppliers. Many firms were

FIGURE 2.14

MARAD NO. MA79SAC00039

PLANNED PROJECT SCHEDULE

Task	Sub-task Descriptions
1.0 Development of Test Evaluation Methodology	1.1 General identification & categorization of O_2 analyzer types 1.2 Test vessel(s) & boiler(s) selection 1.3 Selection of potential boiler sensor installation location 1.4 Determination of at-sea test and evaluation period 1.5 Identification of required analyzer performance data/criteria 1.6 Development of log sheet formats and data logging instructions 1.7 Identification of suitable O_2 analyzer test and calibration stds.
2.0 Selection and Procurement of Oxygen (O_2) Analyzers	2.1 Brief industry survey of O_2 analyzer types available 2.2 Determination of analyzer types suitable for shipboard evaluation and application 2.3 Review of candidate O_2 analyzers 2.4 Final selection and procurement of O_2 analyzers Analyzer Delivery Time
3.0 Installation of Oxygen (O_2) Analyzers	3.1 Final selection of boiler sensor installation location 3.2 Development of analyzer installation requirements & plans 3.3 Analyzer installation 3.4 Analyzer start-up and verification
4.0 Extended Endurance and Performance Testing of Oxygen (O_2) Analyzers	4.1 Liason with vessel operator and analyzer suppliers 4.2 Visits to test vessel(s) 4.3 Preliminary data screening
5.0 Development of Performance Data and Criteria for Shipboard Oxygen (O_2) Analyzers (Final Report)	5.1 Final data reduction, review, and analysis 5.2 Development of O_2 analyzer performance, data, criteria 5.3 Preparation of draft final report 5.4 Submittal of Final Report
Project Management	Project coordination, monthly reports, task reports, administration Quarterly financial reports Mid-term briefing

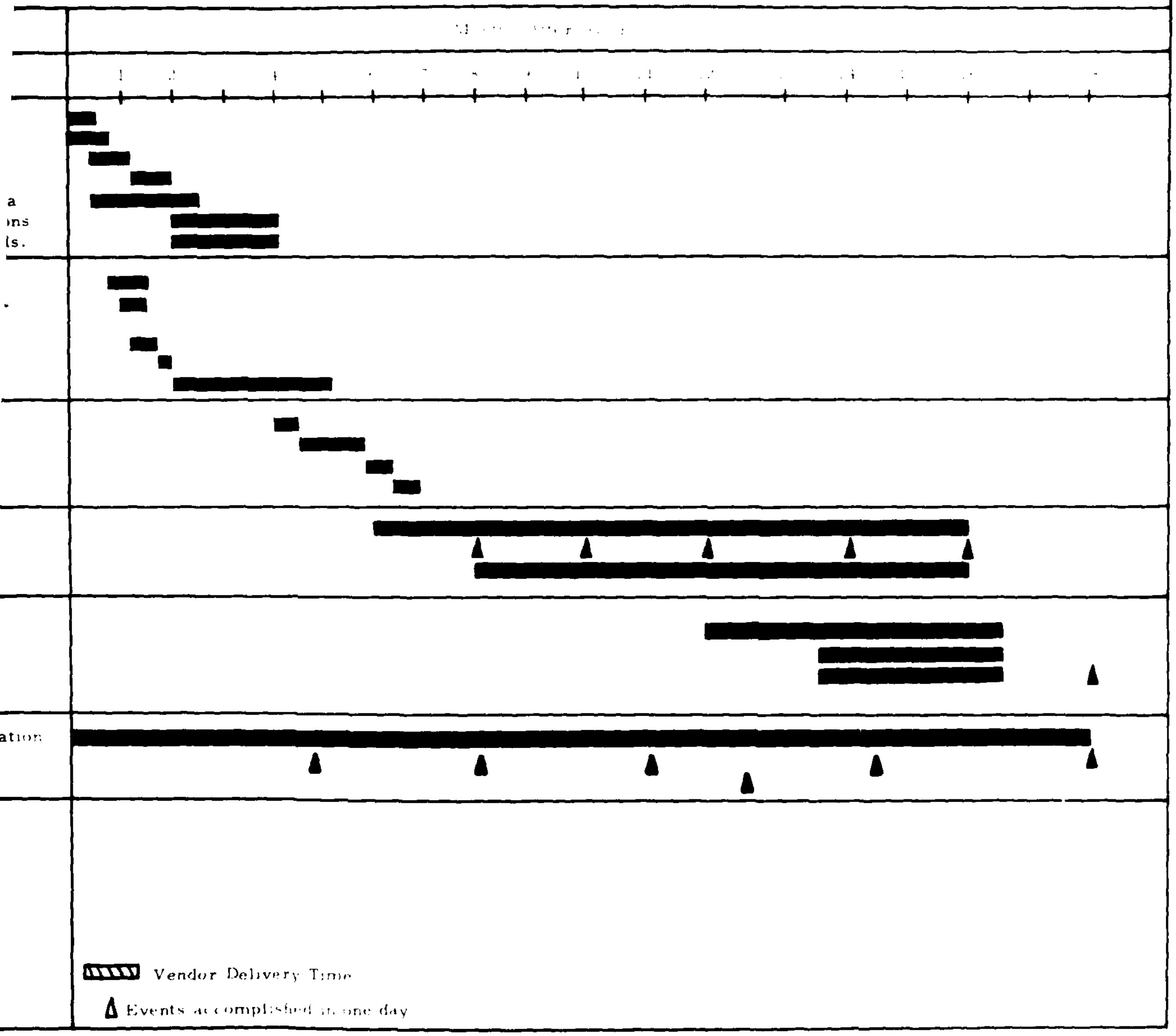
Vendor Delivery Time

Events accomplished in one

ƚURE 2.14

ƚO. MA79SAC00039

D PROJECT SCHEDULE



also contacted by telephone. In those instances where products offered were primarily for medical science, laboratory analysis, dissolved oxygen content of water, high temperature glass kilns, steel blast furnaces, flame safety, and pure gas applications, the manufacturer indicated and/or agreed that these systems were not suited for stack gas analysis applications. These systems were immediately eliminated from consideration. Manufacturers whose equipment line included oxygen analyzers felt to be generally acceptable for the program were sent requests for technical information, pricing, delivery time and performance specifications. Approximately fifty (50) manufacturers were contacted in this manner. Twenty (20) manufacturers responded with technical information.

To clarify and aid in quantifying the final selection process a matrix was formulated with twleve selection criteria headings under which each of the twenty initially screened analyzers were evaluated for final selection. Figure 2.15 presents a sample of this selection matrix. The following criteria are included.

* Sensing Principle
* Location/Method of Sampling
* Range
* Quoted Accuracy/Repeatability
* Support Systems Required
* Method of Display
* Service/Calibration
* User Experience
* Availability/Delivery
* Cost/Cost Share
* Suitability for Marine Service

As can be seen the selection criteria for the most part were based on characteristics and features associated with each analyzer. However, these characteristics also had to be weighed against the practical schedule and budgetary considerations of the program which as a result were also factored into the selection matrix.

The final selection of the eight (8) analyzers to be used in the test was simplified as a result of two of the manufacturers withdrawing their products from consideration. A third unit was eliminated because the operator felt that it required too many support systems and as such would place a hardship on the vessel's resources. The eight (8) analyzers finally selected were all considered to be of equal rating as determined from information developed by the selection matrix. At this time

FIGURE 2.15

MARAD CONTRACT NO. MA79SAC00039

AT SEA TEST AND EVALUATION OF OXYGEN (O_2)

O_2 SELECTION MATRIX

MANUFACTURES NAME	SENSING PRINCIPLE	LOCATION / METHOD OF SAMPLING	RANGE	QUOTED ACCURACY REPEATABILITY	SUPPORT SYSTEMS REQUIRED	METHOD OF DISPLAY	SERVICE / CALIBRATION	E

FIGURE 2.15

CONTRACT NO. MA79SAC00039

EVALUATION OF OXYGEN (O_2) ANALYZERS

O_2 SELECTION MATRIX

ORT EMS IRED	METHOD OF DISPLAY	SERVICE / CALIBRATION	USER EXPERIENCE	AVAILABILITY/ DELIVERY	COST / COST SHARE	SUITABILITY FOR MARINE SERVICE DUTY	REMARKS

2

a decision was made to use all eight of the remaining analyzers in the test. All parties participating in the program reviewed and commented on each of the eight (8) analyzers which were determined to be suitable for at-sea testing and evaluation, and their selection was unanimously agreed upon.

The development of test methodology, requirements and criteria described previously in Section 2.2 was conducted simultaneously by the contractor with the analyzer selection task. This work was also reviewed and approved by cognizant Government and operator program personnel.

2.3.2 Analyzer Procurement and Installation

After final review and selection of the analyzers as described in the previous section, the eight (8) units were ordered by the contractor in mid-October, 1979. Delivery from date or order placement ranged from six (6) to ten (10) weeks. The units were shipped from the factory to the contractor's facility for sanitation. The intent of this action was to remove all possible means of manufacturer identification from the analyzers, instruction books and manuals and other related material so as to put the at-sea test and evaluation on a generic basis and to prevent wherever possible the comparison of individual analyzers on a brand name basis.

As each unit was received it was assigned a color code after all trade names, markings, logos, model numbers and insignia that would divulge the identity of the analyzer manufacturers had been removed. The eight (8) colors used to identify the different machines were:

Gold	Black
Red	White
Blue	Green
Yellow	Orange

The units were carefully repacked in their original shipping cartons (shipping cartons were also "sanitized" of trade names and model numbers), along with two copies of the instruction manuals. Not all analyzer manufacturers provided fully equipped analyzers. At this time missing accessories were procured and packed for shipment with the units. The units were then shipped to the operator's warehouse to await installation onboard the test vessel.

During this sanitation period a detailed review of the analyzers as shipped for completeness (e.g., some analyzers were not equipped with a means for displaying sensed oxygen values or with ancilliary components such as air pressure regulators) and for completeness, quality and clarity of installation, operation and troubleshooting instructions and schematics was conducted. Their conformity to applicable regulations and standards including American Bureau of Shipping (ABS), and U. S. Coast Guard (USCG) rules and regulations and the Institute of Electrical and Electronic Engineers (IEEE) Standard 45 were also determined at this time.

The installation of the analyzers (predicated on the earliest availability of the test vessel) onboard the S. S. STELLA LYKES took place in March 1980. The installation was conducted under the continuous supervision of contractor and operator program personnel, in accordance with the General Installation Specification (see Appendix C). This work took approximately one week to complete and was started in New Orleans and completed in Houston. Figures 2.16, 2.17, 2.18 and 2.19 present typical layout diagrams, electrical one lines and air piping schematics used to direct the installation. Manufacturer's recommendations and standards were precisely followed throughout the installation. The installation went smoothly for the most part. Installation difficulties resulting from peculiarities in individual analyzers were noted for inclusion in the analysis of test data and results.

The initial start-up of the oxygen analyzers was felt to be critical to the test results. To insure the fairness to all manufacturers and to obtain higher confidence in the test results, manufacturers technical representatives were requested to start and certify that their systems had been correctly wired, plumbed, and mounted in accordance with the recommended procedures. The units were started and verified in Houston. Lakes Charles, Port Arthur and New Orleans during an extended coastwise voyage from March 15th through 30th, 1980. The calibration of the units was also checked by the manufacturers' technicians at this time using the calibration gases supplied by the contractor. All eight (8) units tested called for calibration gas as the proper field check. In addition to gas checks, the units were tested electrically, as per individual instructions. Contractor personnel monitored all work accomplished by the technicians and their service reports were retained as certification of the units' proper installation and start-up. At the completion of each start-up and calibration check and installation verification, the control cabinet was sealed by the vessel's Chief Engineer in the presence of Government and contractor personnel.

FIGURE 2.16
PLAN VIEW OF O_2 ANALYZER SENSOR
RELATIVE UPTAKE LOCATIONS

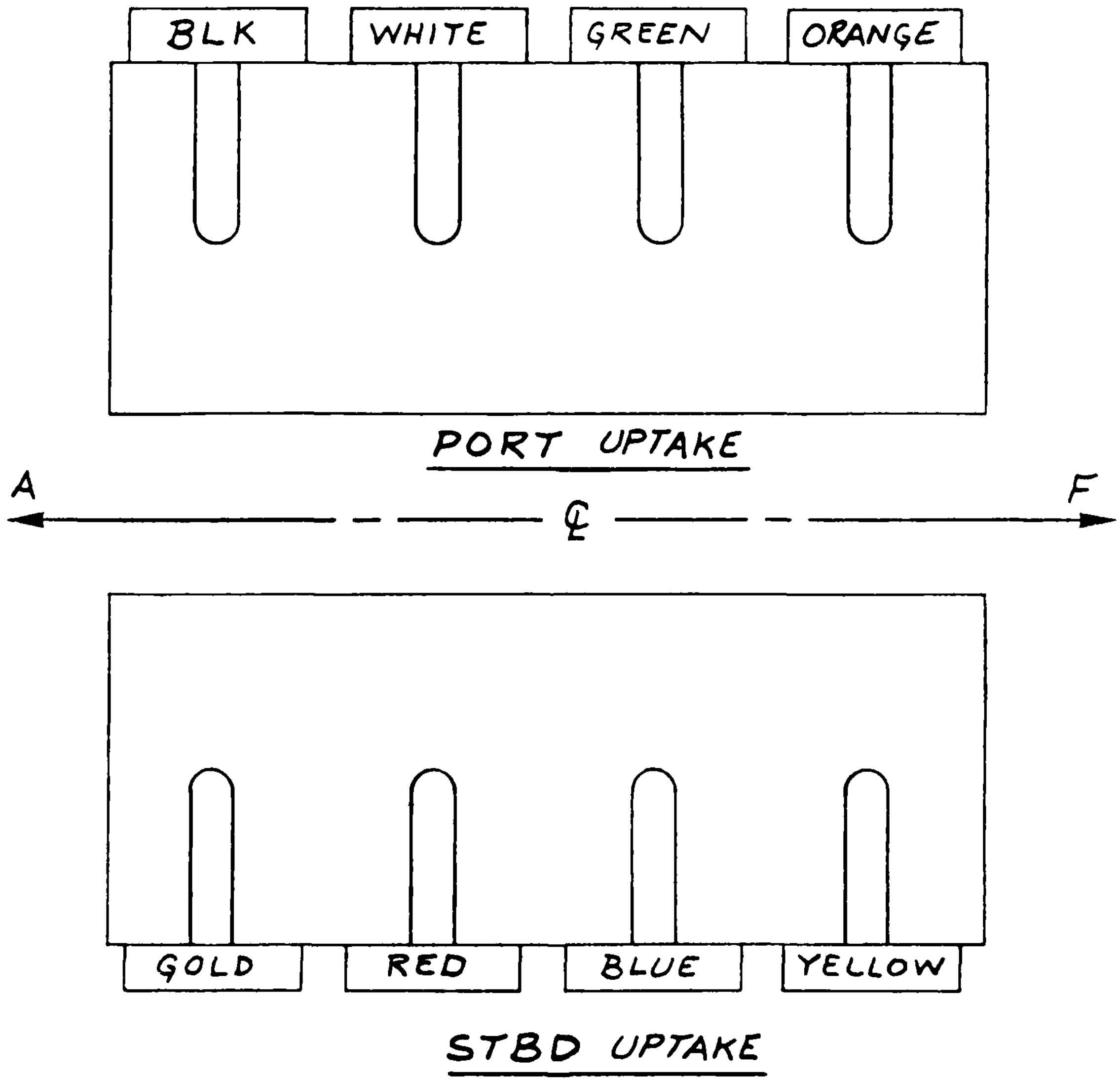


FIGURE 2.17
ANALYZER CONTROL CABINET MOUNTING ARRANGEMENT

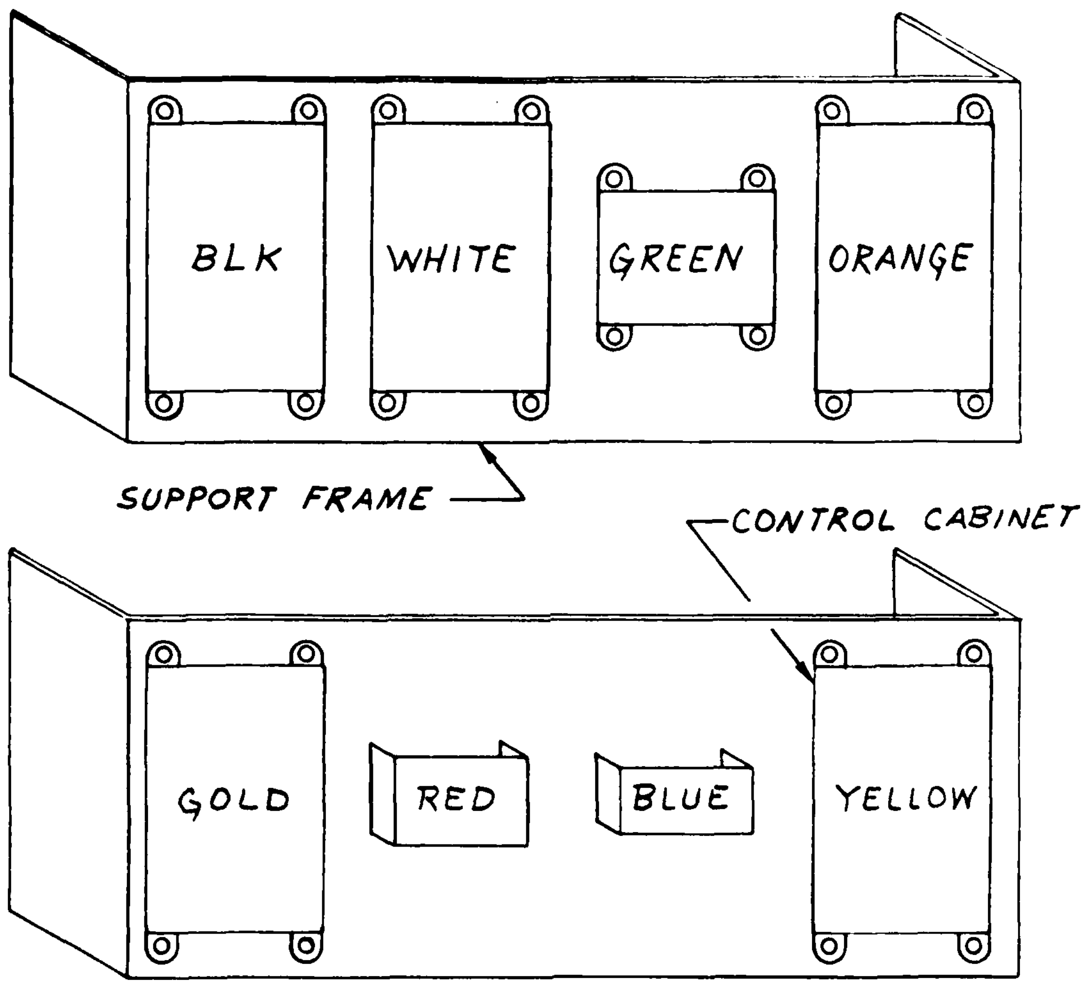
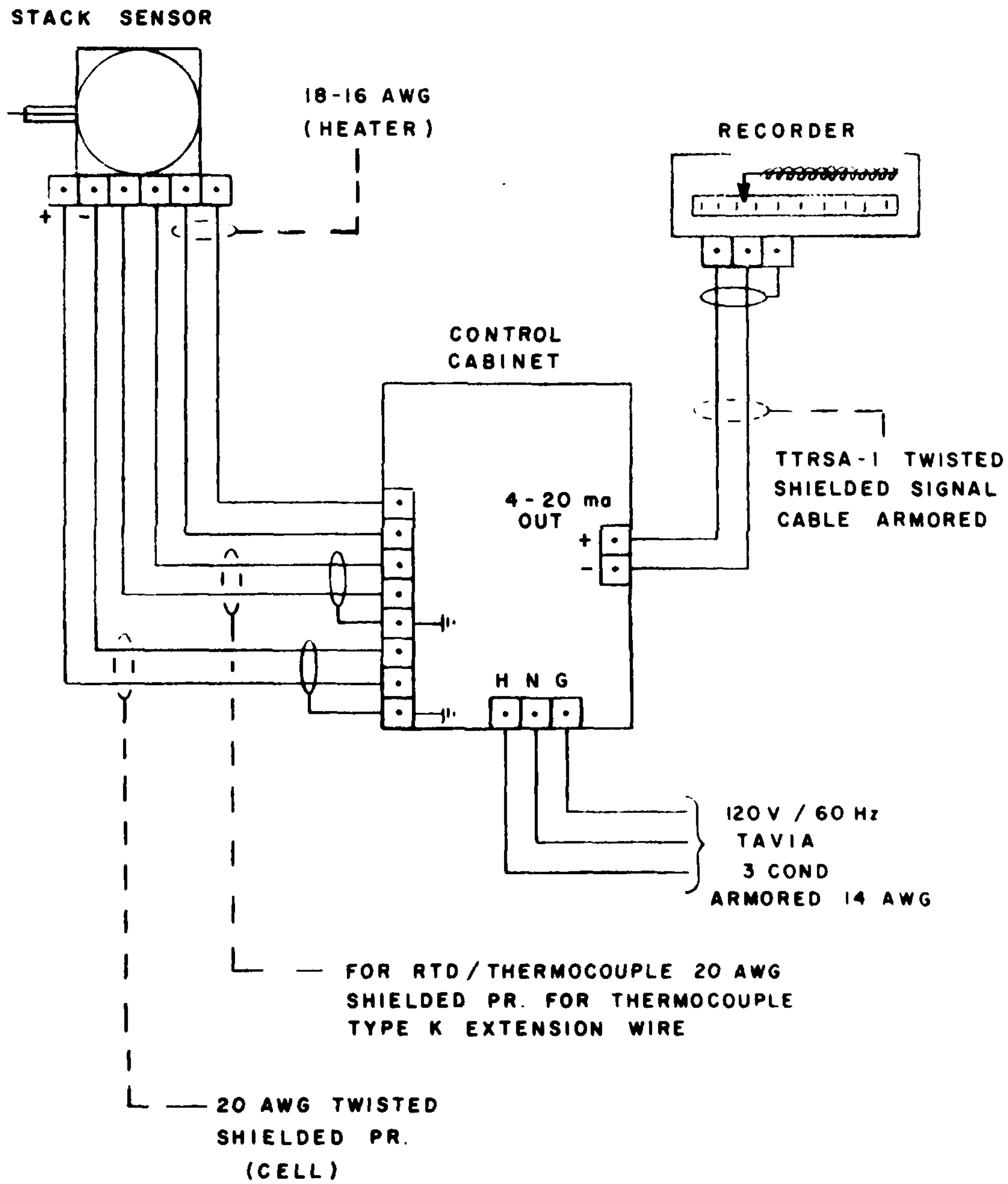


FIGURE 2.18
TYPICAL ANALYZER INSTRUMENTATION ELECTRICAL ONE-LINE DIAGRAM



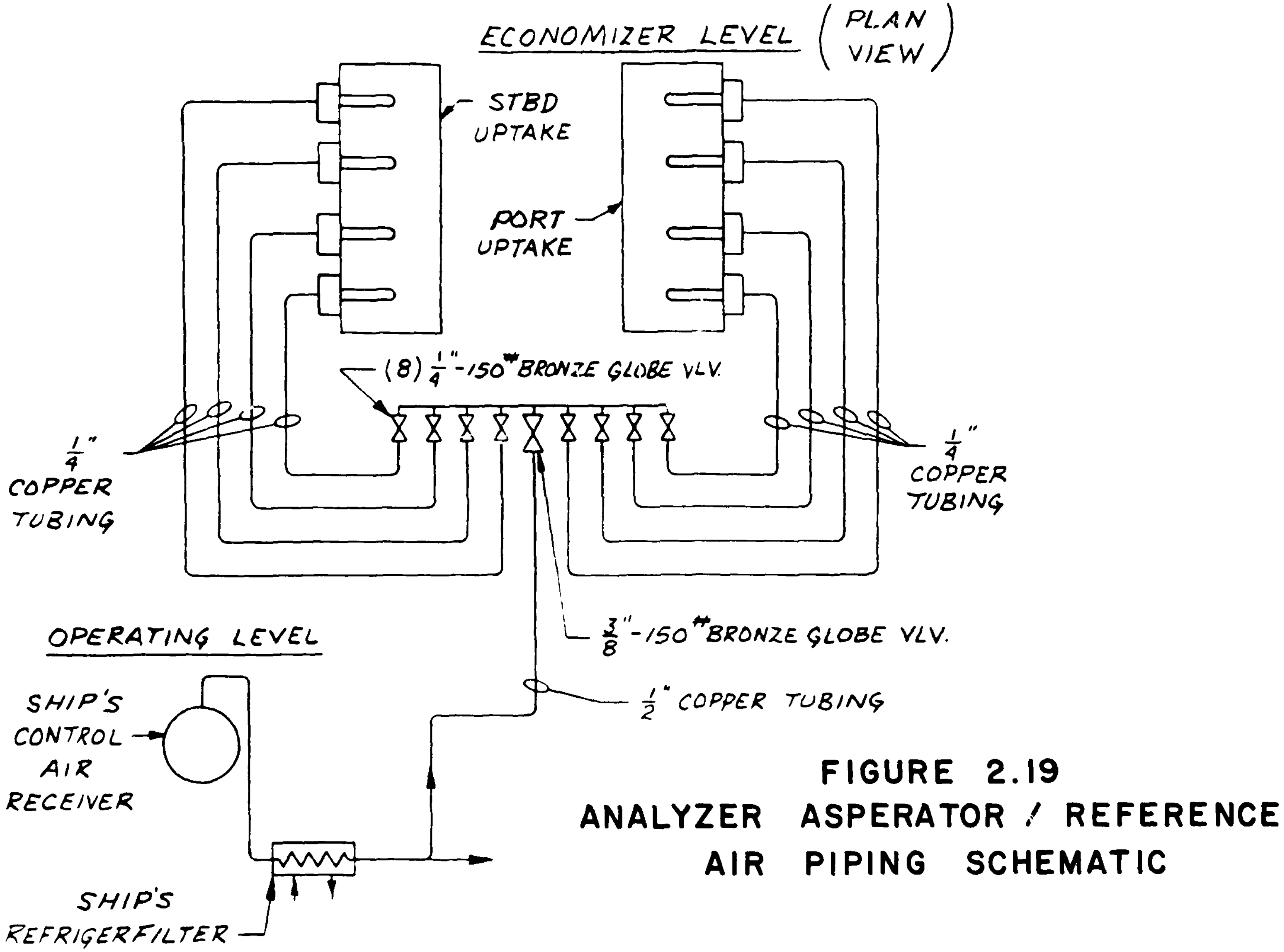


FIGURE 2.19
ANALYZER ASPERATOR / REFERENCE AIR PIPING SCHEMATIC

Training of the Chief Engineer and Engine Cadet during this period was enhanced by their additional exposure to the analyzers as they were being installed and through contact with manufacturers' representatives. Two sets of instruction books for each analyzer were placed onboard for use primarily in the operation and limited servicing required for each analyzer. The majority of instruction and training was concerned with detailing of data recording and test installation service requirements. Servicing of the test equipment was limited to adjustments and repairs to the external air systems and pressure regulators, the 115 VAC wiring, cleaning of the external surfaces of the components, renewal of the continuous data recording system consumables and advanced notification of operator shoreside and contractor personnel of additional support requirements such as manufacturer service for units that failed at sea.

2.3.3 At-Sea Endurance Testing

The continuous at-sea endurance testing of the eight (8) selected zirconium oxide based oxygen analyzers ran from April, 1980 through January, 1981. Data was recorded onboard the vessel during all operating conditions including steady state steaming, maneuvering and in port via the automatic data logging system and manually by designated shipboard personnel. In addition, voyage letters updating test progress and reporting any failures or other difficulties were prepared by the Chief Engineer and forwarded to the contractor via the operator's cognizant program personnel.

At the termination of each voyage during which the endurance testing was carried out contractor personnel met the vessel at various U. S. Gulf Coast ports to conduct and or coordinate the following activities including:

* Obtain automatically and manually recorded data for the voyage.

* Perform analyzer calibration checks.

* Replenish test consumables such as log sheets and strip chart paper and pens.

* Conduct training of new crew members assigned to the program as required.

* Debrief operating personnel concerning their observations

and opinions of analyzer performance during the previous voyage.

* Coordinate the availability and supervise the repairs and service made by authorized service representatives on analyzers that failed or malfunctioned during the previous voyage.

* Update cognizant Government personnel as to progress to date.

Throughout this at-sea test and evaluation period the contractor screened the data collected on the previous test voyage to ensure that it contained all of the information required to obtain the stated program objectives. This screening also allowed for the addition or deletion of data types being logged, if required. Finally, this process provided for the identification of developing problems and trends in both the automatic data logging system and the analyzers, as they occured.

Figures 2.20, 2.21, 2.22, 2.23, 2.24, and 2.25 highlight various components of the continuous automatic data recording and analyzer test installation onboard the S. S. STELLA LYKES during actual underway operating conditions.

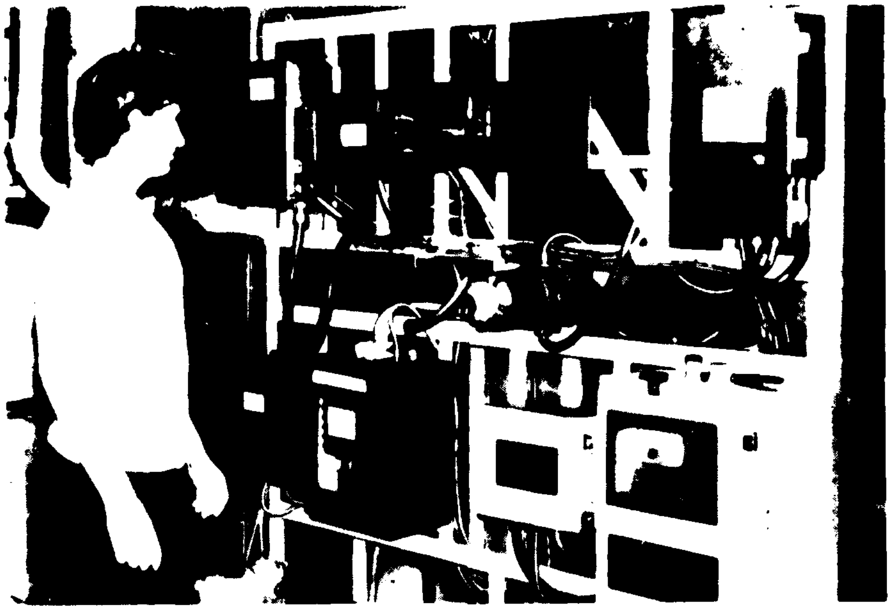


FIGURE 2.20
RACK MOUNTED
ANALYZER CONTROL CABINETS

FIGURE 2.21
ANALYZER SENSORS MOUNTED IN
THE STBD BOILER UPTAKE CASING

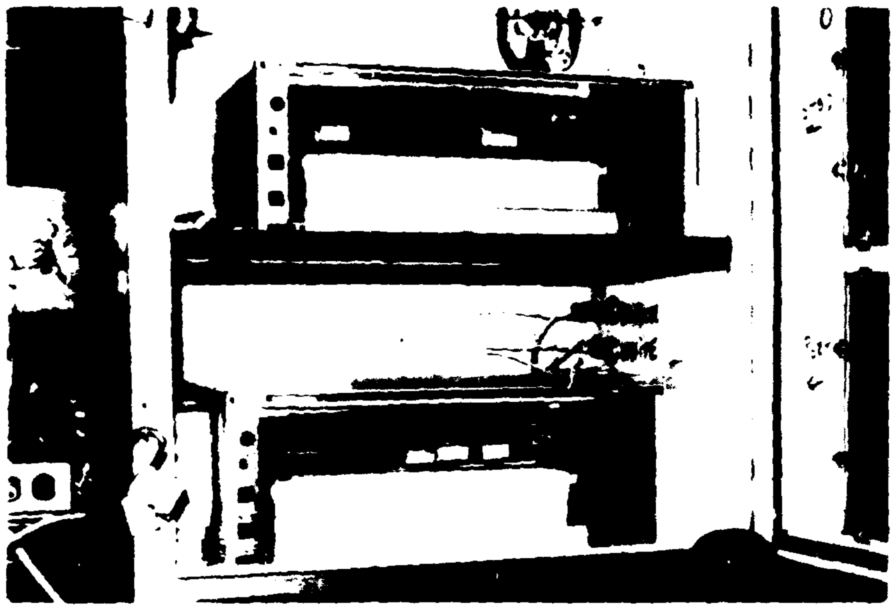


FIGURE 2.22
AUTOMATIC STRIP CHART RECORDERS
MOUNTED IN THEIR NEMA-4 ENCLOSURE

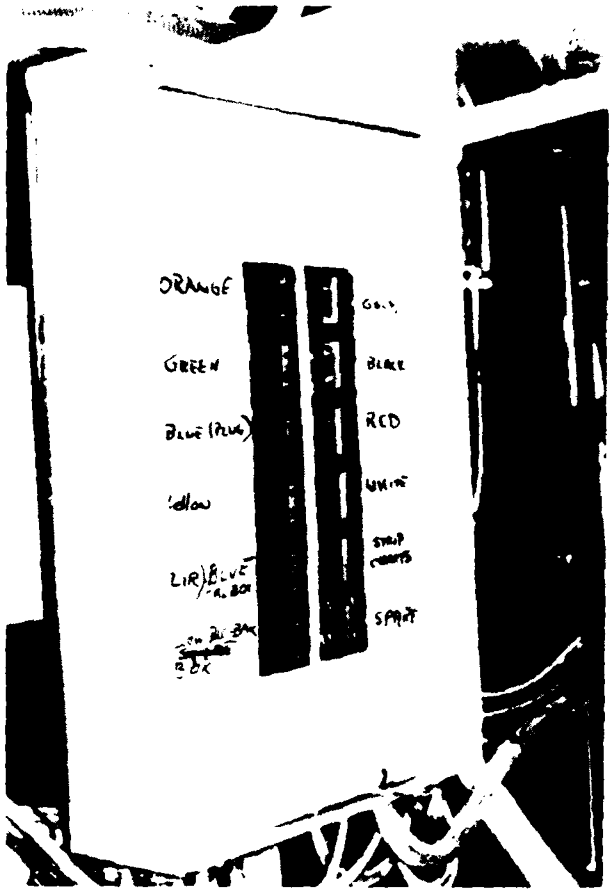


FIGURE 2.23
POWER DISTRIBUTION PANEL
AND INDIVIDUAL CIRCUITS FOR
ANALYZERS AND ACCESSORIES

FIGURE 2.24
ANALYZER CALIBRATION CONTROL
CABINET ARRANGEMENT

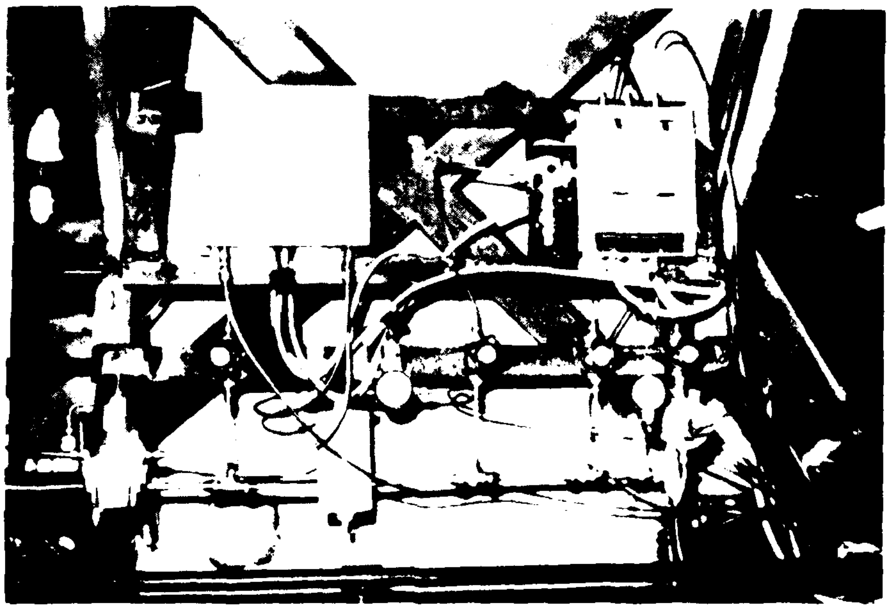


FIGURE 2.25
TYPICAL ASPERATOR INTERRUPTER
CONTROL BOXES

3.0 PROGRAM RESULTS

3.0 PROGRAM RESULTS

The program results described in this section are based on performance criteria previously described in Paragraph 2.2.3 and the qualitative and quantitative data obtained during the ten (10) month at-sea endurance testing phase. The at-sea evaluation ran for a total of 305 days. This total breaks down into 170 days of steady state at-sea operation at approximately 60 to 85% of rated boiler load, 16 days maneuvering, 104 days in port and 15 days of outage due to shipyard and other boiler shutdown periods. 290 operational days per analyzer or a total of 2320 analyzer test days were available for the program. Of the total available, 1918 analyzer days of testing were actually accrued due to underway failures of malfunctions of three (3) analyzers. Table 3.1 below breaks down the total operational days on a per analyzer basis.

TABLE 3.1: BREAKDOWN OF TEST DAYS AVAILABLE PER ANALYZER

Analyzer Color/Type	Boiler	Test Days for Which Data Was Available
1. Blue/In-Situ	Starboard	290
2. Red/Extractive	Starboard	290
3. Yellow/Extractive	Starboard	290
4. Gold/Extractive	Starboard	127
5. Black/In-Situ	Port	245
6. White/In-Situ-Extractive	Port	96
7. Green/In-Situ	Port	290
8. Orange/In-Situ	Port	290
	TOTAL	1918 Days

The results obtained are discussed in detail in the following paragraphs for each of the evaluative criteria.

3.1 In-Service Performance

In-service performance evaluation of each analyzer was based on the analysis of qualitative and quantitative data gathered for the following characteristics: ability to operate continuously and unattended, response and sensitivity to % O_2 changes in the sampled gas and the ability to produce accurate, stable readings.

All of the unit's evaluated were more than satisfactory in their ability to operate unattended. The extractive units as a precautionary step had the air supply filters or moisture extractors for their asperator circuits blown down daily. Those in-situ units (black and white) which were provided with meter calibration circuits and semi or fully automatic calibration features (blue analyzer) also allowed for quick and more frequent check and adjustment of meter calibration by the operating engineer, if desired. All of the analyzers were capable of providing a continuous read-out of % O_2 concentration. Two of the units furnished (green, yellow) did not provide a meter for displaying this value. However, they were recorded continuously on the automatic strip chart recorders. Both of these analyzer manufacturers will provide a read-out of % O_2 as an option for the basic analyzer package.

Timed tests were conducted at the end of each voyage to determine response times. Response time for this evaluation was considered as the length of time required by each analyzer to reach 90% of the final steady state value of a known concentration of oxygen. This was accomplished by introducing a flow 3% O_2 calibration gas into each unit which had been reading the oxygen content of the boiler flue gas and timing each machine's response to the introduction of this known O_2 concentration change. This check was performed for each unit at the end of each test voyage if the analyzer was functioning. For example, if the value read in the uptakes prior to introducing the calibration gas was 11.2%, a stop watch would be started when the reading began to fall after flowing the calibration gas over the cell and was stopped when the indicated reading reached 3.8% O_2. This procedure was then repeated after the indicated value reached its final steady state value by securing the flow calibration gas and re-introducing the boiler flue gas. Table 3.2 presents the response time of each analyzer as averaged over the test period.

The extractive analyzers were generally quicker responding than the in-situ devices probably due in part to the faster flow of sample gas across the cell induced by the air asperator loop. Also, response time tended to increase a direct function of time in continuous service for each analyzer. It should be noted that this test was based on response as observed on the display face or strip chart. Actual cell voltage response is typically on the order of milli-seconds.

TABLE 3.2: ANALYZER RESPONSE TIMES

Analyzer	Average Response Time	Quoted Response Time
Gold	5.6 seconds (1)	(2)
White	5.8 seconds (1)	5 seconds
Black	7.1 seconds (1)	8 seconds
Red	12 seconds	11 seconds
Blue	12.3 seconds	8 seconds
Orange	12.8 seconds	3 seconds
Yellow	13.2 seconds (3)	8 seconds
Green	13.7 seconds (3)	1 second

(1) Based on partial data due to analyzer failure
(2) Not provided
(3) Read from test strip chart recorders

Warm-up time was recorded for each analyzer during initial start-up at the beginning of the at-sea evaluation and just prior to rip-out of the test installation at the end of this period. Start-up time is the length of time required by an analyzer to reach a fully operational steady state condition from a cold condition. The in-situ devices were found to be considerably faster than the extractive units. This is probably due in part to the considerably higher than ambient temperatures maintained in the cell heater and the temperature stabilization time required for extractive units due to their location external to the uptakes. Table 3.3 presents the results of these warm-up tests. No significant difference in these times was noted for the initial and final tests.

TABLE 3.3: AVERAGE ANALYZER WARM-UP TIMES

Analyzer	Average Warm-Up Time	Quoted Warm-Up Time
Blue	22 minutes	60 minutes
Orange	26 minutes	30 minutes
Black	31 minutes	60 minutes
Green	33 minutes	30 minutes
White	35 minutes (1)	60 minutes
Gold	57 minutes (1)	60 minutes
Yellow	64 minutes	120 minutes
Red	72 minutes	120 minutes

(1) Initial start-up only; not functioning at the end of the test.

Through-out the at-sea test and evaluation period during underway steady state steaming conditions, shipboard operating personnel recorded a once daily % O_2 reading using the non-continuous orsat wet chemical method (accepted as a standard for such organizations as the EPA and ASME). Initially, this reading was intended to be a test standard for the actual reading of oxygen concentration in each boiler uptake at a given time. These readings were then to be compared to test analyzer values of % O_2 as taken from the strip chart data at the same time (0400) each day at which the orsat readings were recorded. Approximately 100 days of data were extracted and compared during which the boilers were operated at 80 to 85% of their rated capacity. It was determined that for about 95% of the data reviewed the test analyzers read considerably higher than the orsat method. This is shown in Table 3.4 as average readings for the analyzers and orsat oxygen concentration in each boiler.

TABLE 3.4: AVERAGE ANALYZER AND ORSAT READING COMPARISONS

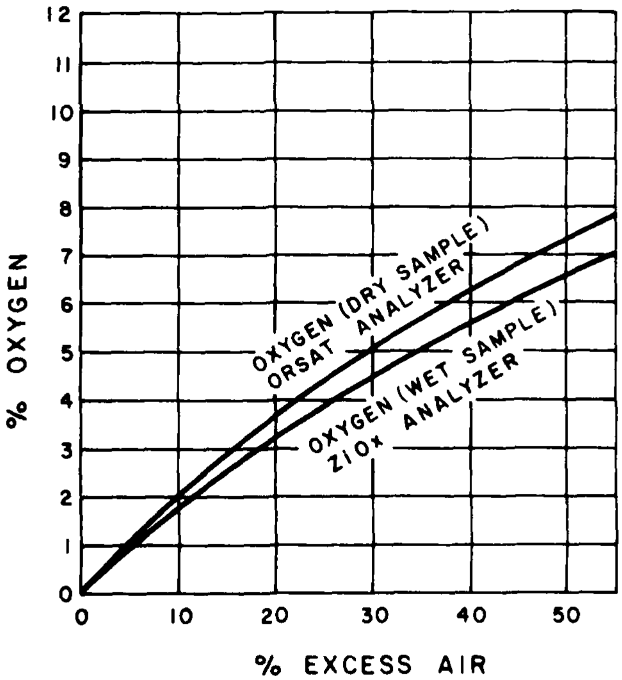
Analyzer	Boiler	Average orsat % O_2	Average Analyzer % O_2
Blue	Starboard	2.11	3.24
Red	Starboard	2.11	3.74
Gold	Starboard	2.11	3.96
Yellow	Starboard	2.11	3.52
Black	Port	2.34	3.15
Orange	Port	2.34	4.02
Green	Port	2.34	3.19
White	Port	2.34	3.22

The obvious trend in orsat readings being below the analyzer values (by as much as 70%, see Figure 3.1) was the reverse of what should have actually occurred. Orsat is a dry sampling technique. Gases removed from the stack for orsat analysis are filtered and cooled to ambient or slightly above ambient engine room temperature. This results in condensation of water vapor, a product of combustion which has been cooled well below its dew point temperature, to be removed from the sample gas flow prior to entering the orsat chemical reagent apparatus. The result is a reading that can be as high as 8 to 10% above a wet gas reading (depending on the fuel type) taken with a device such as a zirconium oxide analyzer. In the case of this type of analysis wet gas flows across a cell maintained at a constant temperature between 1100 and 1500°F. At this temperature the water vapor stays in vapor form and passes over the cell as part of the flue gas. Figure 3.1 presents the relationship of wet and dry flue gas oxygen analysis to excess air supplied for combustion.

These factors along with the absolute values of the orsat % O_2 readings versus analyzer % O_2 readings also made orsat unacceptable as the standard for this evaluation. This is due to the fact that the orsat system is potentially subject to significant human error in such forms as operation and use of the system, interpretation of results or failures to properly maintain chemical reagents and filtering and other support systems. The zirconium oxide analyzers as tested here eliminate almost all of this error source. This possibility is further supported by the relatively close grouping of average analyzer % O_2 values for each boiler as presented previously in Table 3.4. Based on this analysis, accuracy in terms of correctness of reading versus the true value over the course of this at-sea endurance test is felt to be more representative in the form of the calibration drift checks presented later in Paragraph 3.3.

FIGURE 3.1

WET vs DRY GAS MEASUREMENT OF OXYGEN AS AN INDICATOR OF EXCESS AIR



3.2 Repeatability

Initially repeatability was felt to be available from analysis of the strip chart trace recordings of actual boiler flue gas content. However, to obtain a true picture of the repeatability of an analyzer, data is required across the complete ope: ting range of the machine. The at-sea data for boiler flue gas oxygen content recorded during steady state operation ranged from about 2.5% to 4.5% O_2. In port stack gas oxygen content was maintained from 12% to 15% O_2. Sample traces have been provided in Figures 3.2 and 3.3. This lack of data from prolonged operation at various oxygen concentrations from .5 to 20.9% O_2 resulted in the utilization of the detailed calibration check data obtained at the end of each test voyage to calculate a repeatability for each unit which was to represent the characteristic's average for each machine value over the duration of the test. The gold unit which failed during all three voyages of this evaluation was eliminated from repeatability determinations as it was considered as an essentially new unit after each servicing.

Briefly, readings were taken from the analyzer displays or strip charts where no other display was provided while flowing 2% O_2, 3% O_2, 10% O_2, 15% O_2 calibration gas and air, 20.9% O_2 across the cell. This procedure was then repeated starting with air and working back to 2% O_2. The data for each analyzer was then used to determine repeatability by calculating the root mean square deviation of the errors recorded for the ten samples of gas flowed. This calculation is expressed mathematically below.

$$\text{Repeatability} = \sqrt{\frac{\sum_{1}^{N} (X_1 - \bar{X})^2}{N}}$$

Where:

N = number of samples
$\bar{X}$ = % O_2 value of calibration gas
X_1 = actual reading recorded
$(X_1 - \bar{X})$ = Indicated Value Less the True Value

Table 3.5 presents the average repeatability as a percentage of the reading of each machine as determined over the course of the at-sea endurance as well as quoted repeatability where available. Generally, repeatability of the machines tended to improve as the at-sea test and evaluation progressed. All of the recorded errors were found to be on the high side.

FIGURE 3.2

TYPICAL % O_2 TRACE RECORDING AT SEA (STBD BOILER)

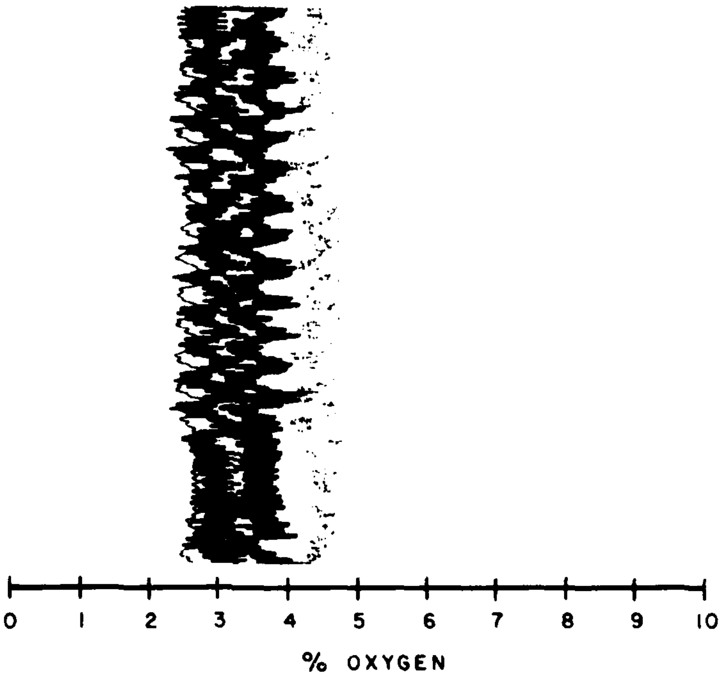


FIGURE 3.3
TYPICAL % O_2 TRACE
RECORDING IN PORT
(PORT BOILER)

TABLE 3.5

AT-SEA ENDURANCE TESTING
CALCULATED AVERAGE REPEATABILITIES

Analyzer	Test Repeatability	Quoted Repeatability
Red	+ .43%	± .2%
Blue	+ .53%	(4)
Green	+ .61%	(4)
White	+ .77% (1)	(4)
Black	+ .78% (2)	± .1%
Orange	+ 1.51%	(4)
Yellow	+ 1.66%	(4)
Gold	(3)	(4)

(1) Based on one voyage.

(2) Based on two voyages.

(3) No data available due to failure on each voyage.

(4) Not provided.

3.3 Calibration and Recalibration Requirements

Calibration was checked on each analyzer during start-up and at the end of each voyage during the test period utilizing the calibration gases previously listed and described in Section 2.2.3.1. The use of certified calibration gases of various % oxygen content in an inert background was unanimously recommended and agreed on by all analyzer manufacturers as being the only accurate and meaningful method to check calibration drift and adjust the calibration of a unit, if required. Table 3.6 presents a composite of results for each analyzer as the average error in percent O_2 over the range of calibration gases flowed.

Generally, the calibration drift of those units which functioned continuously throughout the test period tended to improve with time.

The complexity involved with recalibrating an analyzer to correct the observed drift varied greatly. Generally, the process of calibration checking and recalibration, by design, was more complicated for in-situ analyzers than for extractive analyzers.

This is due to the fact that the physical placement of the zirconium oxide cell in the flue required more extensive calibration accessories than did the extractive analyzers. The in-situ analyzers (blue, green, black, orange, white) required reference gas and calibration gas to be delivered to either side of the cell in very specific flow rates. The manufacturers of the in-situ machines addressed this need by supplying calibration accessories as standard items. All of these machines were equipped with calibration gas flow meters, valves and fittings. The calibration panel was the most sophisticated approach provided and the type easiest to operate. Typically, the calibration accessories were mounted on either a panel or in a cabinet so that the reference and calibration gases could be permanently connected and activated by simply opening a petcock or turning a valve. One calibration panel (blue analyzer) was electronically operated with control circuitry and mini-solenoid valves for span and zero checks. All of the analyzers that were equipped with calibration panels could have the panels mounted remotely from the sensor (uptake area) and closer to the control panel (console area) which would be preferable from an operational standpoint.

The extractive analyzers (red, gold, yellow) required that calibration gas be led to the sensor calibration port, while the other side of the cell was exposed to atmosphere (air). None of the extractive units came equipped with flow meters, isolation valves, tubing, pressure regulators, etc., required to properly meter the calibration gas across the cell. However, flow rates and calibration gases were specified. Also, this

TABLE 3.6

ANALYZER CALIBRATION DRIFT
CHECK RESULTS

Analyzer Color	Average Readings, $\Delta \pm \%\ O_2$				Average For Test %	Quoted Design (2) %
	Start-Up 3/30/80	Voyage 1 6/10/80	Voyage 2 9/18/80	Voyage 3 1/26/81		
Red	0	+ .7	+ .6	+ .2	+ .375	± .1/mo.
Blue	0	+ .6	+ .4	+ .6	+ .43	± .3
Green	0	+ 1.2	+ .4	+ .3	+ .425	(3)
Orange	0	+ 3.0	+ .5	+ .9	+ 1.1	± .3
Yellow	0	+ 2.7	+ .5	+ 1.3	+ 1.13	(3)
Black	0	+ .1	+ 1.1	- - -	- - -	(3)
White	0	- 1.2	(1)	(1)	- - -	(3)
Gold	0	(1)	(1)	(1)	- - -	(3)

(1) Analyzers failed during the voyage and were repaired and restored to their start-up condition prior to the beginning of the next voyage.

(2) Long-term calibration drift.

(3) Not available.

arrangement required that the calibration gas be started at the analyzer sensor (uptake area) and that the adjustment be made several levels below at the control cabinet.

None of the analyzers evaluated were supplied with calibration gas by the manufacturers. These were obtained separately from a specialty gas company for the at-sea test and evaluation. Once set up, calibration checking of the analyzers was felt to be well within the capability of a typical shipboard operating crew. However, the complexity associated with the adjustment of calibration as determined by observing service technicians and a review and analysis of instructions outlined in the instruction manuals provided, varied greatly.

The calibration procedures provided for all of the analyzers with the exception of the blue machine required manual readings of electrical components and circuitry within the control cabinet. Simplistically, these adjustments centered on recalibration of the meter or display circuit and the zirconium oxide cell. The meter calibration allowed for adjustment of the meter to read the value of the calibration gas flowed. Depending on the analyzer, adjustments for zero and span were provided. The black (in-situ) and white (in-situ with an asperator loop) analyzers provided dials on the control cabinets doors which allowed for meter circuit adjustment without opening the control cabinet. The remainder, excluding the blue analyzer, required adjustment via potentiometers mounted on Printed Circuit Boards (PCB's) inside the control cabinets.

Because seven (7) of the eight (8) analyzers measured cell output (% O_2) while holding cell temperature constant, calibration checking also involved checking cell output voltage versus temperature. This is accomplished utilizing a digital Volt/Ohm Meter (VOM) to read cell output in millivolts while flowing a certified calibration gas through the hot cell and comparing the measured voltage to a cell output voltage versus oxygen concentration curve for a fixed temperature. These curves are supplied by the vendor. The temperature compensating circuitry is adjusted until a milli-volt reading matching that of the milli-volts shown on the calibration curve is obtained. Essentially these adjustments raise or lower the cell temperature to obtain the desired milli-volt output signal. These adjustments were also made in the control cabinets on PCB mounted potentiometers.

The blue analyzer had as a standard feature automatic calibration features for meter zero and span. The requirement for checking and adjusting cell outputs due to cell heater temperature changes was unnecessary as the unit's electronic componentry continuously solved for cell temperature as well as oxygen content utilizing the Nernst Equation.

Recalibration procedures for all but two (2) of the units as presented in the instruction manuals were felt to be within the capability of the ship's operating crew, after on-site training and indoctrination by a factory service representative. The recalibration and adjustment procedures as presented in the green and yellow analyzer instruction manuals were felt to be written in a very complex manner and would be difficult for shipboard personnel to interpret and utilize. This is a very important consideration due to the fact that, as with operational reliability, the capability to adjust and calibrate these units onboard rather than depending on shoreside service, is an absolute requirement for a marine application.

3.4 Maintainability

A wide range of factors were evaluated as part of maintainability under the general areas of installation and operational requirements, quality and completeness of instruction manuals and scheduled maintenance requirements for each unit.

3.4.1 Installation and Operational Requirements

Sensor Mounting Brackets: Three (3) (white, yellow, gold) out of the eight (8) analyzer manufacturers delivered their units without sensor mounting brackets. Of the three units without brackets, one (gold) required threaded pipe, nipples and unions. The yellow analyzer required a three-inch pipe flange. The pipe fittings required for these brackets would most likely be found aboard ship. The white analyzer shipped without a bracket required a shop fabricated spool piece, special flange and a gasket for the main in-situ probe and another return pipe assembly for the sample flue gas return to the stack. This analyzer sensor was the most difficult of all sensors to mount because of the special brackets and return assembly and the requirement for two stack penetrations.

Control Cabinet Enclosures: The control cabinets housed the electronic printed circuit cards, meters and wiring. One (1) (blue) of the eight (8) manufacturer's control cabinets was a non-acceptable semi-protected enclosure with exposed electrical terminals on the back of the cabinet. The acceptable enclosure for the control cabinet was waterproof, as defined in "IEEE 45 Recommended Practice for Electrical Installations on Shipboard". NEMA 4 enclosures were preferred for this service.

Two manufacturers whose control cabinets were NEMA 4 enclosures had no window in the door of the cabinets in order to view the display of the oxygen meter. Without a window, the door would have been repeatedly "dogged and undogged" to read the meter. It is more likely that the door would have been left ajar which would make the enclosure, at best, a general purpose enclosure. Window kits were purchased and installed in the doors of these two control cabinets in order that the doors could be sealed shut during the test while allowing the oxygen meter readout to be viewed.

Cable Requirements: The cabling required by the various analyzers can be grouped in two categories; power and control/signal. The power, and in some instances the control cables, are not supplied as part of the standard analyzer package. The ship is expected to supply acceptable grades of cables for this purpose. The power cable used for all analyzers (115V AC service) was TAVIA-4, (3-conductor, 14 AWG, armored) power and lighting cable. This cable is generally found aboard ship. Signals from the control cabinets to strip chart recorders, and on two analyzers (blue, black) from the temperature control modules to control cabinets, were conducted by TTRSA-1 (one twisted shielded pair of signal conductors, armored). This type of cable is not commonly found aboard ship and would have to be ordered from shoreside.

The control cable, unlike the power or signal cable, is a unique combination of conductors that connect the sensor to the control cabinet circuitry. This cable is a non-stock item and must be custom laid-up in accordance with the manufacturers specifications. The attitude towards supplying this vital piece of equipment by the manufacturers varied. The preferred approach is to have the manufacturer supply this control cable as standard equipment. As standard equipment the cord came with a molded quick disconnect end at the sensor to facilitate ease of disassembly for repairs to the sensor. This was felt to be the best approach for in-situ-sensors as they had to be completely removed from the uptake to affect repairs. At the control end, these vendor supplied control cords came with numbered wire tags to make hook-up easier and faster.

Four (4)(black, white, orange and green) of the eight (8) analyzers came equipped with satisfactory control cables that had quick connects at the sensor end and numbered tags at the control cabinet end.

Of the remaining four analyzers, two (blue, gold), were shipped without a control cable, one (red), was equipped with non-acceptable cable and the last (yellow) was equipped with four-feet of cable. The non-acceptable cable was a laid-up cable of the correct multi-conductors, but the cable covering was soft poly-vinyl. To make this cable acceptable, it was pulled through spiral wound metallic one-inch flex-tube with a plastic covering.

The analyzer with four feet of control cable was meant to have the controls next to the sensor and as such the control cabinet could not be remotely located. A junction box and forty-five feet of armored control cable was added to the unit in order to mount the control cabinet remotely with the seven other units. In the case of two analyzers sent without the required specialty cable, the operator would be expected to order and assemble up to four different types of cable. The four cables would then have to be pulled through protective flex-tubing and equipped with special end fittings. The process of making up these control cables was time consuming and expensive. Non-standard wire sizes and types are not always available in short lengths, and minimum purchases of 100 to 500 feet may be necessary. The control cable is well worth buying as an accessory from the analyzer manufacturer rather than to be made-up by an electrician in the field.

The importance of installing the correct control cable cannot be overstressed. The cable is the link between the sensor and electronic controls which carries the cell voltage (O_2) signal, sensor heater current, and heater temperature signal. Many of these cables require shielding and precise sizing. The cable from the sensor to the control cabinet, in most cases, should not be over 50 feet in length because resistances of the conductors may start to affect analyzer calibration. The units equipped with control cables were factory calibrated with their own cable, thus insuring a better chance of being in calibration once field installed. Units equipped with pre-made-up control cables specified that the cable, if too long, should not be shortened and that coiling up the excess would retain the factory calibration of the system.

Air Pressure Regulators: Air pressure regulators were required for all of the analyzers for the reduction of ship control air (110 psig) to the pressure required by the analyzer for asperation and/or calibration purposes. Six (6) of the eight (8) analyzers came with high quality air pressure regulators and fittings. The two (gold, white) that did not were provided with standard adjustable air pressure regulators. An air pressure regulator is a required inexpensive item that should come as standard equipment with all units.

3.4.2 Instruction Manuals

The instruction manual provided with each unit is a very important facet of every analyzer. The manual should, as a minimum, relate how to install, operate and calibrate the analyzer. In general, all of the books furnished accomplished this. The sections of an instruction manual that ultimately will be of the greatest importance and value to the operator, and result in cost savings in the long run are the maintenance and repair sections. Only three (red, white, orange) instruction books were felt to be complete in this respect. The following is felt to be a complete check list of information which should be furnished besides the standard installation, operation and calibration data.

- * Customer specification and analyzer serial number.
- * Complete spare parts list.
- * Recommended spare parts list.
- * List of accessories.
- * Common errors and problems guide.
- * Troubleshooting guide.
- * Part location and numbering guide.
- * Recommended maintenance schedules.
- * Spare parts ordering information.
- * Calibration curves (cell voltage versus % oxygen and RTD resistance or thermocouple voltage versus temperature).
- * Installation drawings.
- * Drawings:
  - Wiring schematics
  - Interconnecting wiring/PCB schematics
- * Service information including addresses and telephone numbers of area repair facilities.
- * List of materials.
- * Recommended calibration gases and sources.

Two other serious discrepancies were observed with regard to instruction manuals. The first being that two of the manufacturers (yellow, green) packaged an instruction book from various universal components in their product line that were brought together to make-up the oxygen analyzer. The Table of Contents was a check-off list of a few books and drawings from a much longer list that applied to other assemblies or units. Assembling an instruction book in this manner makes for a discontinuity in the text, confusion and a greater possibility of application error. This is exemplified by the fact that the printed circuit boards in one analyzer (green) were revised while the instruction book provided schematics of older units. The second (green analyzer) serious deficiency in an instruction book was an exaggeratedly complex electronic method of checking the performance of the printed circuit boards and calibration. A high degree of familiarity and proficiency with electronics terminology and theory would be required to understand the instructions as written. The instructions are of very limited value if not written in terms more easily interpreted by shipboard personnel.

3.4.3 Scheduled Maintenance Requirements

The periodic maintenance required was felt to be minimal for all analyzers once installed. This consisted mainly of keeping surfaces free of soot and draining moisture extractor filters on the control air lines supplied for asperation and calibration, daily. The black and white units as described previously provided control cabinet dials for adjusting meter circuit calibration in a permanent installation with a built-in calibration loop. These units would allow for a daily check of meter calibration. The blue analyzer had automatic features and these could be operated at will. Generally cell output should be calibration checked and adjusted if required once monthly.

3.5 Repairability

With failures occurring in three (3) (white, gold, black) of the eight (8) analyzers and the program guidelines which specified repair by authorized service technicians, only, quantitative data in this category was somewhat limited. However, qualitative data obtained from a review and analysis of design features, installation requirements, calibration and recalibration procedures, instruction manuals, etc., provided a substantial basis from which to identify repairability features desirable for marine service.

The gold (extractive), white (in-situ with asperator) and black (in-situ) analyzers suffered major upsetting conditions that rendered the units inoperable during portions of the test. The gold analyzer was twice repaired for a faulty furnace temperature control circuit. The temperature control circuitry is designed to maintain 1400°F (760°C) in the heated space around the cell. Both failures were "shorts" in the temperature circuit control. A third failure, identical to the first two, on the final voyage was not repaired. The furnace temperature control is accomplished by an electronic comparitor circuit. The furnace is equipped with an embedded thermocouple. When the furnace is too hot (above set point) the thermocouple output exceeds the set point, and turns the furnace off. When the thermocouple output is below the set point the heater output is increased. Ideally, the output of the thermocouple should match the set point and the comparitor circuit keeps the furnace on set point with some limited cycling of the furnace voltage. When the system shorts, the voltage to the furnace is on full all of the time. Serious damage occurred to the cell, furnace, thermocouple, wiring and housings as a result of the furnace over-fire causing complete failure of the analyzer.

Four other analyzers (yellow, orange, green, white) used the RTD thermocouple comparitor type control system to regulate the temperature in the furnace with successful results. The problems that plagued the temperature circuit in the gold analyzer appears to have been the fault of the quality of the components used and not the general theory employed. The white analyzer became inoperative due to blockage of the asperator with soot, rust and corrosion. The white analyzer, unlike the other in-situ units, required an asperator induced flow of flue gas over the cell. The asperator was fitted outside of the heated path that the gases must travel. Failure to heat the asperator air and asperator made them cold sinks where the moisture in the flue gas condensed. This condensed moisture trapped soot to form a very crusty, corrosive scale which continually plugged the flue gas path and corroded the asperator tip. The problems associated with this model analyzer stem from it not being designed to handle dirty wet flue gas. An internal asperator, made of corrosive resistant metal and operated with heated air would have provided better reliability. This failure was repetative and occurred on all but the first voyage.

The black analyzer suffered an electronics failure which put it out of service for the final 45 days of the at-sea test and evaluation period. This failure occurred to a PCB component in the meter display and signal conditioning circuitry housed in the control cabinet.

All of the manufacturers offered field repair of their analyzers. However, this statement needs qualification with regard to marine repair, availability and repair expertise. It was found that the larger companies who deal in numerous components as part of their product line were more apt to have local service technicians or service companies whom could offer service and repair of the oxygen analyzer. Whereas for the smaller manufacturers, the technician was dispatched from the factory.

The timing of marine repair and ship's scheduling is difficult to predict. It was found that most factory technicians were in great demand and as such, required a great deal of prior notice to provide service. Factory service was best handled on an appointment basis which for marine repair requirements is totally unacceptable due to the unpredictability of ship's schedules. Also, the cost of factory originated service was found to be much higher than local service. In some instances, service calls from the factory approached one-half (1/2) the total cost of the analyzer and in general, were twice that of local service.

Availability of local repair technicians was another strong point. Often only 24 hours notice is possible, and due to short travel time, it was possible for them to adapt to the ship's arrival and sailing times. However, factory dispatched technicians displayed a greater familiarity and knowledge of the analyzers. Of the four technicians sent from the factory to perform the initial start-up and calibration of the oxygen analyzer, three were rated as good and one as fair. Of the four service local repair technicians, only one could be rated as good, two were fair and the fourth, unacceptable. The factory dispatched technicians also carried spare parts where local technicians did not. The following is a qualitative comparison by analyzer of service and repair expertise as observed over the course of the at-sea endurance testing.

Analyzers Serviced by Local Technicians

Analyzer	Expertise
Yellow	Good
Black	Fair
Green	Unacceptable
Gold	Fair

Analyzers Serviced by Factory Dispatched Technicians

Analyzer	Expertise
Red	Good
Blue	Good
White	Good
Orange	Fair

The service rates for a technician ranged from $30 to $48/HR as of March 1980. Travel for one service call is a function of distance; the highest travel expense bill encountered was $1, 085, exclusive of labor costs.

The cost of a single repair, when factoring the cost of repair parts, can range between 10% to 50% of the initial cost of the analyzer. Therefore, it is essential that the repairability of small malfunctions be within the abilities of and performed by shipboard personnel. It is also suggested when purchasing an analyzer that analyzer manufacturers without local service representatives be querried as to analyzer changeout and factory return and repair of potentially high casualty rate items such as the stack sensor.

The hands-on repairability of the analyzers is a function of the number of components and their location. The location of the control cabinets and electronics were identical for all analyzers. However, the accessibility of the sensor (where most of the maintenance occurs) was better for the in-situ sensor than the externally mounted extractive sensor. The in-situ sensor can quickly be unplugged and unbolted from its stack location and brought to a work bench. The extractive units are made to be repaired in place. Repairing an analyzer in place entails working over and around steam pipes in one of the hottest regions of an engine room. This is not to say that an extractive analyzer sensor could not be designed for easy removal from the uptakes.

3.6 Environmental Influences

All but one of the analyzers held up well under the environmental influences encountered during the testing. Only one of the failures observed (white analyzer) could be directly attributable to an environmental related cause. This was the continually plugging of the asperator provided with the white in-situ as described in Section 3.5. The following is a synopsis of typical ranges and values of key environmental factors in which the test units for the most part functioned successfully.

* Control Cabinet Temperature: 75° to $105^{\circ}F$
* Sensor at Uptake Temperature: 90° to $115^{\circ}F$
* Moisture (Maximum): 95% relative humidity
* Vibration:

Frequency (Hz)	Amplitude (peak-to-peak) (Ins.)
1-4	0.400
4-8	0.100
8-14	0.030
14-30	0.010
30-100	0.002

* Variations in Electrical Power:
  - Voltage $\pm$ 10%
  - Frequency $\pm$ 2.5%
* Stack Gas:
  - Temperature: 290° to $330^{\circ}F$
  - HC: .6 ppm
  - Sootblowing: Ringleman 3
* Ship's Service Air:
  - Pressure 90-110 psig
  - Control Air Filtered and Coalesced

The most difficult environmental influences for the analyzer to cope with were hydrocarbon and soot contained in the flue gas. Hydrocarbons are gaseous by-products of incomplete combustion. The heated zirconium oxide cell, maintained at between 1100 and $1500^{\circ}F$, was at a sufficient temperature to cause hydrocarbons to rapidly oxidize. The rapid oxidation around the cell depleated the surrounding gas of oxygen, causing a shift in oxygen reading toward a lower value. Enough hydrocarbons will make the analyzer read zero. The level of hydrocarbons necessary to cause a zero reading would also produce heavy black smoke in the boiler. Sensing "net" oxygen, while hydrocarbons are being burned in the cell, will lead to inaccuracies in the readings. Soot in the flue gas when it comes in contact with the zirconium cell will burn, causing a deficiency of oxygen. The reaction of the analyzer is the same as for hydrocarbons except that the soot burns longer and causes sharper, more rapid movements in the meter readings. Soot ingestion can be protected against with filters in the case of in-situ analyzers, and filters and asperator interruptors for the extractive units. The in-situ units have unglazed porous ceramic filters through which gas could pass but no solids. One of the extractive units (yellow) used a tight mesh screen in the end of the sampler probe. Two (red, gold) extractive units were not equipped with filters. Figure 3.4 presents strip chart data illustrating analyzer hang up after ingesting soot during soot blowing.

Asperation interruption during soot blowing should be provided for extractive type analyzers where the asperator is an air operated eductor which pulls the flue gas out of the stack and across the cell. In most cases the soot blowers are operated twice a day at-sea utilizing steam lances to remove soot and combustion deposits from tube surfaces. By stopping asperation during soot blowing, soot is not ingested and allowed to clog the flow paths in an extractive machine.

Of the three extractive analyzers, only one (yellow) fully addressed this problem and supplied the air solenoids, pressure switches, and instructions to cope with soot ingestion. A second (red) analyzer addressed the problem with a solenoid valve air shut-off but left it up to the customer to supply electrical switches and control wiring. The third (gold) extractive analyzer did not address the problem. Figure 3.5 presents a schematic of a typical asperator interrupter arrangement. Also, the number of parts in an extractive analyzer out-number those in an in-situ unit as the asperator, convection flue gas tubing, air interrupter solenoids, switches, air asperator block heaters and space heaters are not present on in-situ units.

3.7 Presentation of Reading/Information

The following is a breakdown of analyzer % O_2 readout format supplied as standard equipment with each unit.

1. Digital (blue)
2. Panel Analog Meter (red, black, white, orange, gold)
3. Vertical Strip Chart (yellow)
4. None (green)

FIGURE 3.4
TYPICAL ANALYZER HANG-UP DUE TO SOOT INGESTION DURING SOOT BLOWING

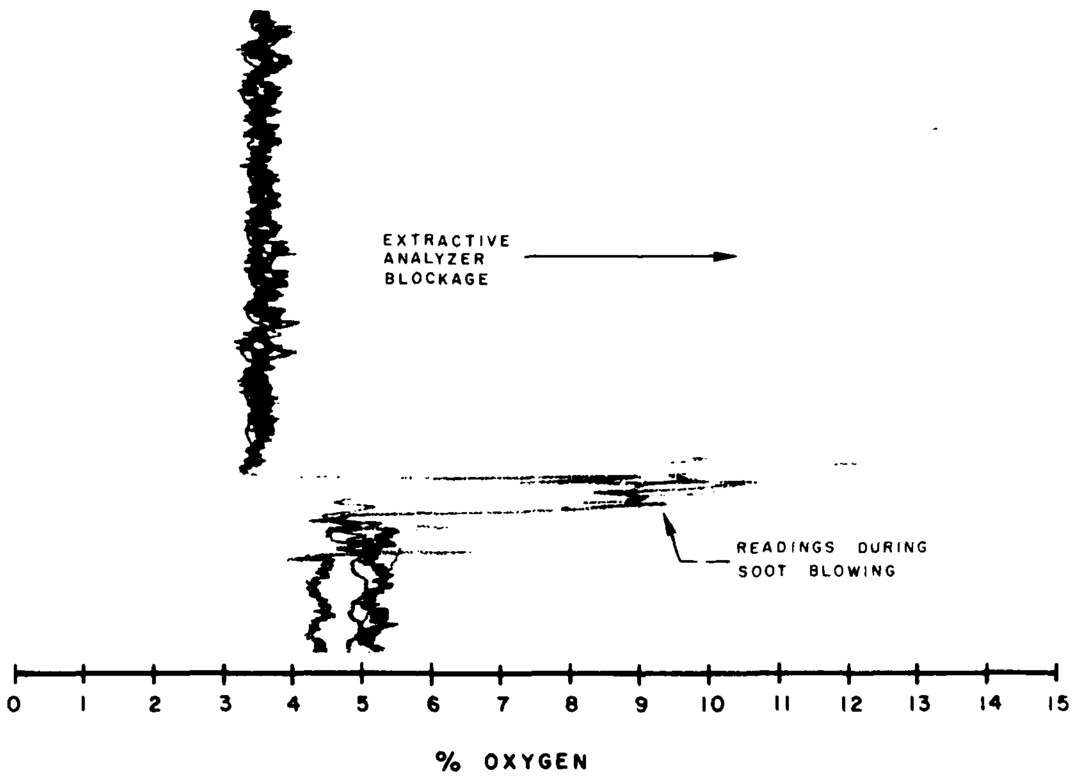
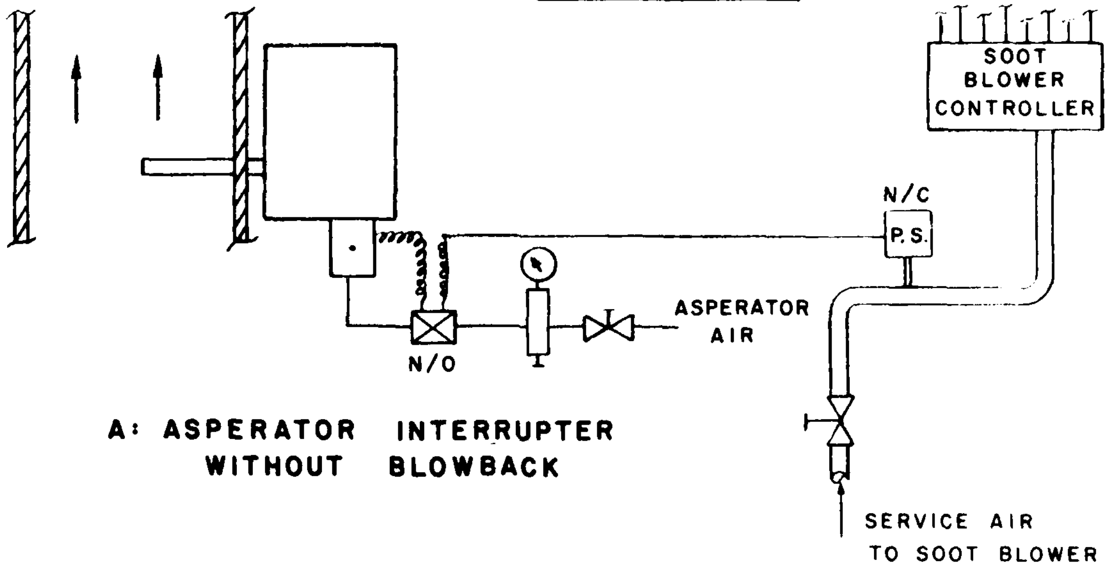


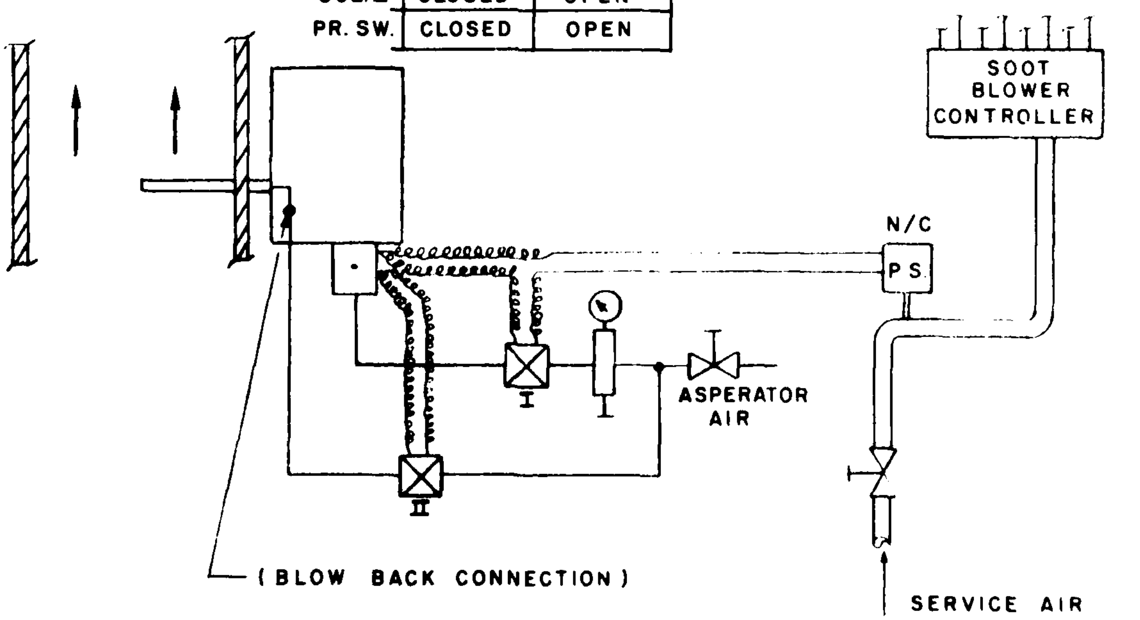
FIGURE 3.5
ASPERATOR INTERRUPTER SCHEMATIC ARRANGEMENT

	NORMAL	SOOT BLOWING
SOLENOID	OPEN	CLOSED
PRESS. SW.	CLOSED	OPEN



A: ASPERATOR INTERRUPTER WITHOUT BLOWBACK

	NORMAL	SOOT BLOWING
SOL. I	OPEN	CLOSED
SOL. II	CLOSED	OPEN
PR. SW.	CLOSED	OPEN



B: ASPERATOR INTERRUPTER WITH BLOWBACK

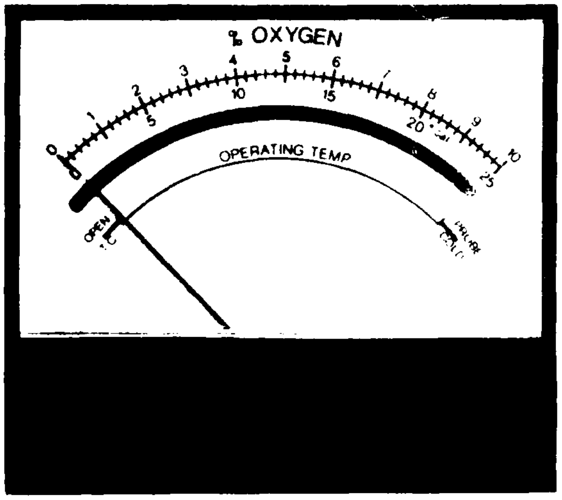
The digital readout was provided utilizing a red light emitting diode (LED) display with a black background. This display could be read to the tenth of a percent oxygen. It could also be read from a greater distance than the panel mounted analog meters because of the one-inch high numerals and contrasting colors. This form of display was the overwhelming favorite of all shipboard operating personnel interviewed. Five (5) analyzers used panel meters, four (black, red, white, orange) with linear oxygen scales and one (gold) had a logarithmic oxygen scale. (See Figure 3.6). These meters were readable close-up and varied in size from 3 to 5 inches. The numerals were approximately one-fourth of an inch in height. On three of the analyzers (black, orange, white) range switches for 0 to 25% O_2 or 0 to 10% O_2 scales were provided which offered increased readability of the display.

A vertical strip chart was supplied with the yellow analyzer. The display on the chart was non-dimensional and read as 0 to 100% of scale. Therefore, some interpretation and mental calculation would be necessary to correlate a chart reading to percent oxygen. This was the least visual and most difficult to read. Also, the requirement for a chart and pen drive adds another complex piece of electronic componentry to the system that must be maintained.

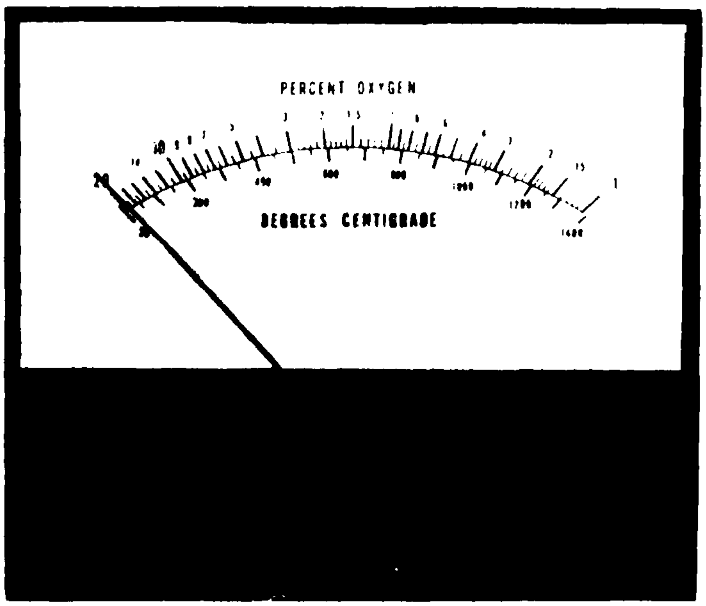
One analyzer (green) came with no display. The only means of measuring oxygen was with a ship's portable multimeter, or as in the case of this test, connection to a strip chart recorder.

The presentation of additional information other than % O_2 that can be obtained by looking at the analyzer control cabinet front without the aid of multimeters or tools varied from unit to unit. The presentation of this additional information was evaluated so that a comparison could be drawn of the potential overall usefulness of each analyzer's display. It was found that the analyzer readouts of percent oxygen alone with no other supportive information does not instill complete user confidence. Short of calibrating the analyzer with calibration gases, other displayed information is felt to be useful to the operator as well as to increase his confidence in the displayed O_2 reading. The displays of the analyzers tested ranged from a unit (blue) that was equipped with self-diagnostics, alarms, and condition indicator lights, to one unit (green) with no presentation of additional data whatsoever. The indications by the engineers onboard the ship were very clear in that they felt that the analyzer with the most complete display was preferred and more correct regardless of whether or not the units with the plainer display were correct. The plain displays (oxygen concentration only) and in austere models (no displays) require a multi-meter and internal checks to ascertain and obtain much of the data readily available on the front panel on the blue unit.

FIGURE 3.6
CONTROL PANEL MOUNTED ANALOG METER DISPLAYS



LINEAR



LOGRITHMIC

The following is information based on operator shipboard and shoreside personnel interviews and opinions that is felt to be the required minimum to be made readily available for a marinized zirconium oxide based oxygen analyzer. Analyzers currently providing some form of these features are also noted.

* Cell Temperature: The cell temperature is the single most important piece of diagnostic information an analyzer can display. The cell temperature is a controlled variable in the Nernst Equation in all but one analyzer (blue) and without knowledge of its proximity to the set point confidence in accuracy may suffer. A temperature readout digitally or on a scale was preferred. This feature was provided by the blue, orange and gold analyzers. Short of a temperature readout in degrees, ^{o}F or ^{o}C, an indicator light either blinking or of variable intensity is also useful in determining if the heating elements were up to or near set point temperature. This feature was provided on the red, blue, orange and white units.

* Cell Resistance: Cell resistance may vary depending upon age and condition of the cell. A resistance check is useful in isolating cell failures as a cause of analyzer malfunction. This was displayed on the blue analyzer.

* Auto or Semi-Automatic Span Zero and Check: This feature provides the user with a quick calibration check. The span mode was for checking the calibration with air on both sides of the cell (reading 20.95%), and zero checks were made by flowing low oxygen content calibration gas across the cell. The difference between a manual calibration and this type of semi-automatic calibration is that the analyzer control cabinet houses the valves, switches and fittings to allow a check to be made quickly and from the control cabinet area. The advantage of this arrangement is that the calibration checks may be done more frequently and quickly. This feature was provided on the blue, black, orange and white analyzers.

* Alarm Conditions (Visual): Alarmed conditions may help the user by bringing his attention to the analyzer display when an upset condition occurs. Only one analyzer (blue) in the test addressed the status and set points of the analyzer operation by providing visual colored alarm lights as well as terminals for additional audio alarms. The status and set points for which the blue unit provided visual

alarms were:

Status Indicators	Color of Light
Optimum oxygen	Green
Early warning (for low oxygen)	Yellow
Alarm (high/low oxygen)	Red

Set Points Lights and Displayed Values:

High/low cell temperature	Set point/display
Early warning	Set point/display
Alarm (high/low oxygen)	Set point/display

Cell temperature, system diagnostics, high-low limit displays and auto-calibration can be of great value to the operator in his ability to maintain and repair an oxygen analyzer. Table 3.7 presents a detailed summary of the display features and options provided with each of the analyzers evaluated.

TABLE 3.7
ANALYZER DISPLAY FEATURES AND OPTIONS

Display	Red	Gold	Yellow	Blue	Black	Green	Orange	White	Recommended As:
Power Switch On/Off	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Standard
Power Light	Yes	Yes	No	Yes	No	No	Yes	Yes	Standard
Temperature Status Light	Yes	No	No	Yes	No	No	Yes	Yes	Standard
Cell Temperature Display Meter	No	Yes	No	Yes	No	No	Yes	No	Standard
Range Selector (Analog)	No	No	No	N/A	No	No	Yes	Yes	Optional
Meter % O_2	Analog	Analog	None	Digital	Analog	None	Analog	Analog	Standard
Other Parameters Displayed									
Low O_2 Light	No	No	No	Yes	No	No	No	No	Optional
High O_2 Light	No	No	No	Yes	No	No	No	No	Optional
Early Warning Light	No	No	No	Yes	No	No	No	No	Optional
Low Cell Temperature	No	Yes	No	Yes	No	No	Yes	No	Optional
High Cell Temperature	No	Yes	No	Yes	No	No	Yes	No	Optional
Cell Resistance	No	No	No	Yes	No	No	No	No	Optional
Calibration Position Switch	No	No	No	Yes	No	No	Yes	Yes	Optional
Convenience Features									
Cell Test Jacks	Yes	Yes	No	No	No	No	No	No	Optional
Exposed Fuse Holder	Yes	Yes	No	No	Yes	No	Yes	Yes	Standard
Calibration Knobs	No	No	No	No	Yes	No	No	Yes	Optional
Calibration Flow Meter	No	No	No	Yes	Yes	Yes	Yes	No	Standard
Calibration Panel	No	No	No	Yes	Yes	No	Yes	Yes	Standard

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations concerning the shipboard application of commercially available zirconium oxide type continuous reading oxygen analyzers to the monitoring of flue gas oxygen content as an indication of excess air are offered based on the data gathered and observations made during the at-sea endurance testing and as described in the previous sections of this report.

- Presently as indicated by the endurance testing results, there are available as off-the-shelf equipment, zirconium oxide analyzers that are capable of providing continuous and reliable service for marine boiler flue gas oxygen content analysis. This was best illustrated by the fact that five (5) of the eight (8) analyzers evaluated operated continuously without failure throughout the ten (10) month endurance test. While all of these units had as standard or optional features many of the requirements felt necessary to assure reliable shipboard service, no single machine had them all. Of the analyzers that failed one was extractive, one was in-situ and one was a combination of both. It was the general consensus of all program personnel involved that the in-situ devices generally appeared to offer the best combination of features with regard to maintenance, repair and calibration checking and adjustment.

- Only one unit provided a digital display format. It was, however, favored over the other analog displays by all of the shipboard operating personnel queried. Two of the units were provided without any means of displaying a % O_2 reading. A continuous analog or digital display of flue gas oxygen content is felt to be an absolute requirement for shipboard application and should not be considered as an optional feature.

- A large part of the reliability obtained from the analyzer during the evaluation is felt to be due to the care and planning with which these units were installed and started. The quality and amount of support information for installation available in the instruction manuals furnished, varied greatly. The analyzer manufacturer should be required, via the purchase specification, to supply this information in detail. The actual installation and start-up [illegible]

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AT-SEA TEST AND EVALUATION OF OXYGEN (O2) ANALYZERS.(U)
APR 81 MA-79-SAC-00039
UNCLASSIFIED MA-RD-920-81038 NL

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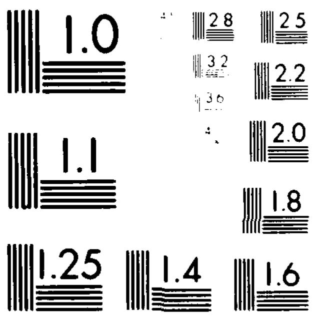
1.0
2.8
2.5
3.2
2.2
3.6
2.0
1.1
1.8
1.25
1.4
1.6

should be accomplished as quickly as possible. Under no circumstances should an installation be attempted on a piece-meal basis, leaving components such as stack sensors in the uptakes in a non-operational state for long periods of time. This approach can create severe operational reliability problems once the unit is placed in service. As part of the purchase agreement an authorized service technician should be provided to check and verify the electrical and mechanical installation, to start the analyzers, to calibrate and adjust the system as required and to provide limited on-site operational and maintenance oriented training for designated shipboard operating personnel.

* Over the course of the at-sea endurance testing obtaining required field service support was difficult. Many manufacturers were unfamiliar with the requirements of keeping up with and meeting a vessel requiring service during a coastwise voyage. A clear understanding of the nature and requirements of marine service should be indicated by a potential vendor. Availability of service at various ports of call should also be identified. The manufacturer should also be required to identify a list of recommended spare parts. These should be placed aboard the vessel. This action ultimately will result in less down time for the analyzer and a potential savings in service costs as shipboard personnel become familiar with the equipment and are able to perform basic repair procedures.

* Calibration gas is the most meaningful standard by which to check and adjust analyzer calibration and to identify any degradation in performance, be it correctness of reading (accuracy) or repeatability. This gas should be provided on the ship in concentrations suitable for checking the complete range of the analyzer; i.e., 2% O_2, 10% O_2 and 15% O_2. (Air, 20.9% O_2, can be used to check the high end.) Calibration, as a minimum, should be checked at least monthly if semi-automatic or automatic calibration features, which allow more frequent checking, are not provided. A complete overhaul and grooming of the analyzer should be performed annually. The cell should be replaced bi-annually.

5.0 RECOMMENDED STANDARD OXYGEN ANALYZER SPECIFICATION

RECOMMENDED SPECIFICATION FOR A MARINIZED OXYGEN ANALYZER

Oxygen Analyzer Sensing Principle:	Zirconium oxide

ELECTRONICS

Power Requirements:	120V AC, ± 10%, single phase 50/60 Hz, $\leq$ 1500 Watts
Range:	0 to 20.9% or 0 to 25% O_2, standard 0 to 10%, optional
Ambient Temperature:	-15°F to 160°F
Electronics Enclosure:	NEMA-4, watertight and dust proof with clear windows to observe reading without opening door.
Radio Frequency Interference:	RFI protected per Mil Specs. C501, R501, R502 and R503, at a field-strength of 15 volts per meter from housing.
Vibration:	Protected for amplitudes and frequencies of these magnitudes: 1-4 CPS (.400 ins.), 4-8 CPS (.100 ins.), 8-14 CPS (.030 ins.), 14-30 CPS (.010 ins.), 30-100 CPS (.002 ins.)
Cell Temperature Controller:	Stabilized solid state components with ambient temperature compensation and fail-safe design to prevent over-heating of cell heater and cell.
Line Switches:	Electronic component isolation switch with power on/off indicator light.
Printed Circuit Boards:	Plug-in type with slide-in access and labeled adjustment potentiometers and test points.

Signal Outputs:	Isolated linear or log 4-20 ma signal with at least 500 ohms load, standard. Optional signal outputs to be made available: 0-50 mv, 0-100 mv, 1-5 ma, 10-50 ma, 0-5 v and 0-10 v.
System Accuracy:	$\pm$ 0.5% oxygen concentration or $\pm$ 5% of measured value.
Display:	1. Direct continuous reading of percent oxygen (% O_2). 2. Cell temperature display. 3. Power on/off indicator light. 4. Analyzer temperature status (ready) light.
Response Time:	90% of full scale in less than 5 seconds.
Repeatability:	$\pm$ .2% of measured value.
Calibration Drift:	Less than .1% of full scale per month.

SENSOR

Power Requirements:	120V AC, $\pm$ 10%, single phase. 50/60 Hz, $\leq$ 1500 Watts.
Ambient Temperature Range at Probe:	-15 to 160^{o}F
Ambient Temperature Range at Probe Head:	-15 to 400^{o}F
Process Gas Temperature:	-15 to 1500^{o}F
Probe Materials:	Probe construction shall be of 304 stainless steel with 316 stainless for internals in direct contact with stack gases. Insulation shall contain no asbestos.
Mounting Bracket:	Flanged bracket and bolt pattern are to be ANSI standard and/or NPT threaded pipe connections. (Standard for short probes.) All required gaskets and bolting shall also be supplied.

Air Requirements: All necessary filters and separators and regulators to reduce 60-110 psi ship's service air to clean dry instrument quality air. Also, roto meters and/or pressure gages at the analyzer for calibration, asperator, and reference gas flows, as required, shall be furnished.

CABLES

Control Cables: A minimum of fifty (50) feet of the multi-conductor control cable from the probe to the electronics temperature control and/or control cabinet shall be supplied with the analyzer. The control cable at the probe end shall be provided with a quick disconnect plug. The cable shall be of an approved type for marine use with protective outer armor per IEEE 45.

SOFTWARE

Installation Drawings: Mechanical prints for the installation of sensor and control cabinet and electrical schematics for power, control and signal wiring shall be furnished.

Instruction Books:

- System Description
- Installation Procedures
- Start-Up Procedures
- Calibration Procedures
- Calibration Curves:
  - Cell mv versus % O_2
  - Temperature versus thermocouple mv or RTD ohms
- Troubleshooting Section
- Maintenance Section
- System Diagrammatics:
  - Mechanical
  - Electrical
- Wiring Schematics:
  - Electrical
  - Electronic

Spare Parts Information:
- Recommended Spares
- Price List
- Ordering Information

Service Information:
- Location and Telephone Number of Service Groups
- Sources of Calibration Gases

MISCELLANEOUS

Calibration Equipment: The analyzer shall be equipped with calibration port rotometers, pressure gages and a control panel as necessary to direct and control the flow of calibration and reference gas to the probe. Calibration gas shall be supplied consisting of oxygen in a nitrogen background, in a concentration specified by the manufacturer. The amount of calibration gas shall be sufficient for one year under normal operation.

Factory Test: The analyzers shall be factory tested for a minimum of three (3) days of continuous analyzer operation to assure that the analyzer is delivered in calibration and is free from all known defects.

Shipping and Packing: The analyzers shall be shipped in rugged containers with expanded foam filler. Plastic wrap shall protect the components from moisture and the intrusion of the foam filler material.

Warranty: The analyzer shall be delivered free of all defects within twelve (12) weeks after receipt of order. The manufacturer shall be responsible for the replacement of all defective parts that fail under normal service and operation for a period of twelve (12) months after receipt of shipment. The manufacturer shall provide service free of charge for a period of six (6) months after installation, exclusive of travel and expenses.

Options:

- Non-standard probe lengths and support brackets.
- Non-standard control cable lengths and protective coverings.
- Automatic calibration control and panel.
- High and low O_2 alarms and lights.
- Cell resistance indicator (digital or analog).
- High and low cell temperature indicator lights.
- Early warning lights.
- Meter range selectors.
- Cell test jacks.
- Multi-probe averaging features.
- Power supply: 220V AC, 50/60Hz.
- High temperature probe to 2800°F.
- Soot blowing interruptor switch for asperator (extractive only).
- Air controlled asperator shut-off (blow back).
- Oxygen calibration gas bottles of recommended (2, 3, 10 or 15) % O_2 in a nitrogen background.

APPENDIX A

SAMPLE ANALYZER TEST QUESTIONNAIRE FOR SHIPBOARD OPERATING PERSONNEL

Oxygen (O_2) Analyzer At-Sea Test & Evaluation

MarAd Contract No. MA 79SAC-00039

Analyzer and Test Questionnaire

Name:______________________________ Rank:________________

Months Service STELLA LYKES:____________________

1. How many times a day did you look at the oxygen analyzer displays? __________

2. Which machine display impressed you the most? ____________________

   Why?____

3. Which machine did you think was the most accurate on the upper tier (Stbd)?

4. Which machine did you think was the most accurate on the lower tier (Port)?

5. Which other machines did you think were accurate?____________________

6. Of the calibration systems, which was easiest to operate?________________

7. Have you ever run an orsat?__________ How long does it take to run a typical O_2 test?______________________________

8. What value is the information an O_2 analyzer gives you?____________________

9. Did you consult the technical manual of the O_2 analyzers?________________

10. Did you use the oxygen analyzers to keep trim or check excess air at sea?________

11. Would you like to see all ships equipped with oxygen analyzers in the future?______

12. What features did you like least about the O_2 analyzers?____________________

APPENDIX B

ANALYZER START-UP CERTIFICATION

HOUSTON NEW ORLEANS GALVESTON

Lykes Bros. Steamship Co., Inc.

SERVICES TO
FAR EAST
MEDITERRANEAN
UNITED KINGDOM
CONTINENTAL EUROPE
SOUTH AND EAST AFRICA
WEST INDIES
NORTH COAST OF SOUTH AMERICA

OWNERS, OPERATORS AND AGENTS

Lykes Lines

CABLE "LYKES"

BRANCH OFFICES
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STELLA LYKES

March 30,1980

TO WHOM IT MAY CONCERN:

On this date the following oxygen analyzer calibration checks were witnessed and the units sealed for the commencement of the U.S. Maritime Administration sponsored at sea test and evaluation of oxygen (O-2) analyzers.

ANALYZER	CAL. GAS FILLED	READING OBSERVED	DATE
Gold	10%	10%	3/28/80
red	10%	10%	3/28/80
Blue	10%	10%	3/28/80
Yellow	10%	10%	3/28/80
Orange	10%	10%	3/28/80
White	10%	10%	3/30/80
Black	10%	10%	3/30/80
Green	10%	10%	3/30/80

Joseph L. Gobroski

Joseph L. Gobroski
Chief Engineer

APPENDIX C

ANALYZER INSTALLATION SPECIFICATION AND REQUIREMENTS

General Specification for Oxygen Analyzer Installation

This general installation specification provides herein the overall scope of work involved in an oxygen analyzer installation for a typical two-boiler shipboard application. Subsequent to the ordering of a particular analyzer a detailed installation description and material list will have to be formulated.

Installation-Mechanical

The oxygen analyzers are composed of two basic parts; the control cabinet and the stack sensor. The control cabinets are to be located adjacent to the operating station, and the sensors are to be located in the boiler uptake above the economizer.

A. The Control Cabinets in general are NEMA enclosures which can be directly mounted to angle iron frames; 2" x 2-1/2" x 1/4" stock has proven satisfactory material for the frames. The frames should be fabricated in a ladder design, mounted upright and welded to the deck. Stiffeners and angle supports should be added as necessary to make the frames solid. Support pieces to be fabricated as required to pick up the mounting ears of the individual control cabinets.

B. The Stack Sensors may be mounted in the rectangular uptake section directly above the economizer expansion joint. To mount the sensors, a square of uptake insulation is removed and the uptake penetration is made by targeting from the mounting flange. Once the penetration is made in the uptake, the mounting flange is welded to the uptake surface, allowing the sensor to be bolted onto the flange. In most cases the mounting flange is of a special design and is furnished by the analyzer manufacturer.

C. Control Air for those analyzers requiring it will be supplied by a 1/4" copper tubing supply line. The control air system (dried, filtered air) will be tapped and valved at the closest point and led to the uptake area near the stack sensors. Each sensor should be provided with its own 1/4" supply line and an isolation valve (1/4" NPT gate valve). Flare or other type tubing fittings and tubing to piping adaptors should be provided as required.

Installation-Electrical

The oxygen analyzer systems will require three types of wiring for power, control and signal.

A. Power Cable for the analyzers should be run from a 115V AC, 60 Hz power source to the control cabinets and in some instances, to the stack sensors from the control cabinets. The cable required is an armored, 3-wire, 15 Amp, 115V AC, 14 AWG cable. This is standard lighting cable throughout the vessel. As an estimate at this time for planning purposes, 250' will be required along with proper termination lugs, approved stuffing tubes, wire way clamps and ties.

B. Control Cable for the analyzers in some instances is of pre-terminated umbilical cord type cable of a special design and size for each individual analyzer. If supplied by the manufacturers, it will only have to be run in the wire ways and "plugged" into the units. A detailed specification should be written for any cable that is not included as a part of an analyzer package. A cable of specific style, as required, should be laid-up before the installation date, tagged and set aside for the analyzer it is to service.

C. Signal Cable is only necessary in certain instances to connect the control cabinet with temperature controls or the isolated output signal to various loads (strip chart recorders or a controller). The approved cable for this service is TTRSA-1 (2 conductor) armored shielded instrument cable, which has one twisted shielded pair of conductors. This cable's armored shield or the outter bonding mesh is to be grounded at one end to eliminate noise and electrical interference.

D. Electrical Hardware necessary for the installation includes but is not limited to stuffing tubes, wire ties, clamps, termination lugs, and switches. Upon identifying the 115V AC panel(s) to be used for power, additional 15 Amp circuit breakers may be necessary if spares are not available. (Two (2) breakers are required).

Contracted Labor

The labor force necessary for the installation of the analyzers aside from owner/operator supervisory personnel and vendor field representatives are estimated to be as follows to complete the installation in a two-day period.

Hot Gang

1 Burner
1 Welder
1 Layout Man

Shipfitters

1 Pipe Man
1 Mechanic

Electricians

1 Qualified Electrician
1 Electrician Helper

The work force may have to be adjusted from the first day to the second day according to the progress of the project.

Manufacturer's Representatives

The manufacturer's representatives should be onhand for technical information, installation assistance and start-up calibration. The representatives should instruct the owner's representative in operation and maintenance.

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